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Based on the best knowledge and experience of applied electricity.

by FRANK D. GRAHAM, B.S., M.S., M.E., E.E.

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Foreword

This series is dedicated to Electrical Progress—to all who have helped and those who may in the coming years help to bring further under human control and service to humanity this mighty force of the Creator.

The Electrical Age has opened new problems to all connected with modern industry, making a thorough working knowledge of the fundamental principles of applied electricity necessary.

The author, following the popular appeal for practical knowledge, has prepared this progressive series for the electrical worker and student; for all who are seeking electrical knowledge as a life profession; and for those who find that there is a gap in their training and knowledge of Electricity.

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The author and publishers here gratefully acknowledge the hearty and generous help and co-operation of all those who have aided in developing this helpful series of Educators.

The series will speak for itself and "those who run may read."

The Publishers.

How to Use This Book

Finder

IMPORTANT

To quickly and easily find information on any subject, read over the general chapter headings as shown in the large type—this brings the reader's attention to the general classification of information in this book.

Each chapter is progressive, so that if the reader will use the outline following each general chapter heading, he will readily come to the information desired and the page on which to find it.

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"An hour with a book would have brought to your mind,
The secret that took the whole year to find;
The facts that you learned at enormous expense,
Were all on a library shelf to commence."

FINDER

CHAPTER 77

Relays

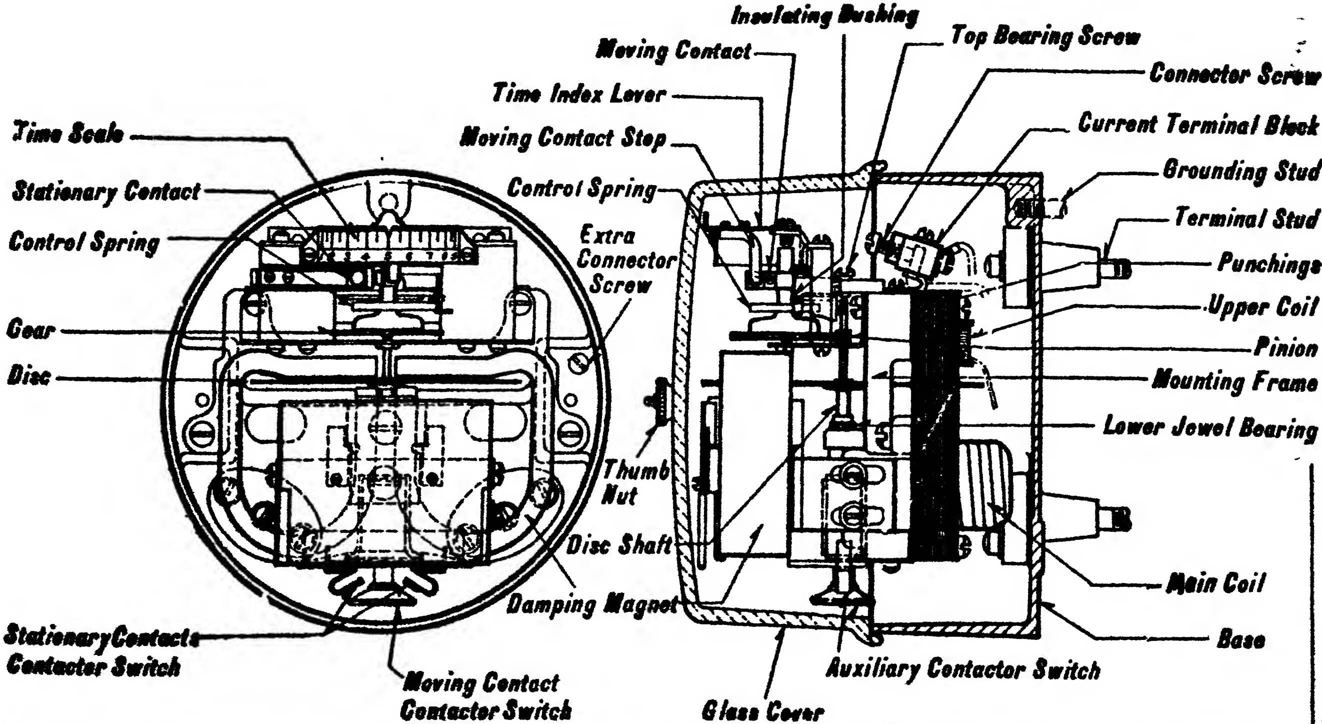
By definition a relay is *a device which* **opens** *or* **closes** *an* **auxiliary circuit** *under pre-determined electrical conditions in the main circuit.*

The object of a relay is generally to act as a sort of electrical multiplier, that is to say, *it enables a comparatively weak current to bring into operation a much stronger current.*

The usual purpose of a relay is to assist in disconnecting that part of an electrical system, in which a fault has occurred, from the rest of the system, with the least possible delay; and to limit such disconnecting to that part of the system that is in trouble. Relays, however, are used for other purposes, such as for signaling; for controlling the operating current of solenoids, motors, etc., and thus reducing the amount of current to be broken by the control switch and the size of leads run to the switchboard; for bell alarm or lamp indication of the automatic operation of oil switches or circuit breakers; and for electrically interlocking switches or circuit breakers.

In the development of relays to meet the various requirements of protection for the circuits and apparatus, there are a number of protection principles upon which their design depends. The advantages and disadvantages of these various principles can be studied, and their particular fields of application defined. These principles are:

1. Over current
2. Inverse time
3. Definite time
4. Directional
5. Differential
6. Ground or residual
7. Over current with under voltage
8. Thermal



FIGS. 4,195 and 4,196.—Westinghouse induction over current relay. *In operation* when a certain amount of current is flowing in the relay coil, sufficient torque is exerted on the disc to start it rotating. The construction of the disc and the contact arrangement is such that the disc must rotate through a given distance before the contacts are closed. Since the disc rotates between the poles of the damping magnet its speed is held constant at all times for any given current flowing in the winding. The damping magnet also serves to prevent the disc overtraveling when the overload is suddenly removed after the disc has begun to rotate. The action of this magnet therefore makes the accurate time adjustment possible with the high torque obtained in the disc. The relay disc has a number of holes punched in it so placed that they assume different relative positions beneath the poles of the electro-magnet as the disc rotates from its initial position. As the disc rotates the spiral spring is wound up and thus the torque necessary to cause the disc to continue to rotate becomes somewhat greater. The action of the holes

Over Current.—The simplest protective principle is that which *uses a so called instantaneous over current* to distinguish between normal and abnormal conditions.*

An example of over current principles is the ordinary series trip coil when used without a time device. Since transient excess current must be considered as normal, it is necessary to make the protective scheme inoperative under these transient conditions. This can be done only by increasing the current setting so as to be out of range of the normal transients; hence schemes involving this principle will never be sensitive to small over currents.

With regard to selectivity, schemes working on this principle will be effective under two conditions. *First*, in cases where the main supply divides into a large number of radial feeds and the fault current on one of the radial feeds is less than the minimum permissible setting of the main supply. The protective device on the main supply can then be set high enough to be inoperative for a fault on one of the radial feeds, and thus service will not be interrupted except in the faulty section. This is usually the case when distribution feeders radiate from a substation bus. *Second*, in cases where there are several parallel feeds, and current flows to the fault in one through all the others; if there be a sufficiently large number of parallel feeds, so that the maximum current due to a fault in one, when divided among the others, will be lower than the minimum setting of the protective device on all feeders except the faulty one. This condition is rarely encountered.

Inverse Time.—The time of operation of relays operating on this principle *varies approximately* **inversely** *with the*

FIGS. 4,195 and 4,196.—*Text Continued.*

in the disc as they pass under the electro-magnet is such that the additional torque required as the spring winds up is provided, thus making the starting current uniform for all initial positions of the disc. In reality the relay requires slightly more current to close the contacts than is required to start the disc in motion from the initial extreme position. This serves to prevent the disc creeping on fluctuating loads, where there are frequent peaks above the relay setting. This feature is an important advantage of the present type of induction relay.

*NOTE.—*Normal conditions* include conditions not only up to the allowable continuous over current, but also transient conditions, which, although involving current values greatly in excess of normal, are not of sufficiently long duration to have harmful effects. This definition includes as normal such currents as motor starting current, the rush of current when a transformer or long line is first energised, and synchronizing current when machines are paralleled.

magnitude of the current. This permits lower current settings, thus giving increased sensitivity.

Under abnormal conditions, if a fault produce a slight over current for a long enough time or a large enough over current for a short time, the protective device operates.

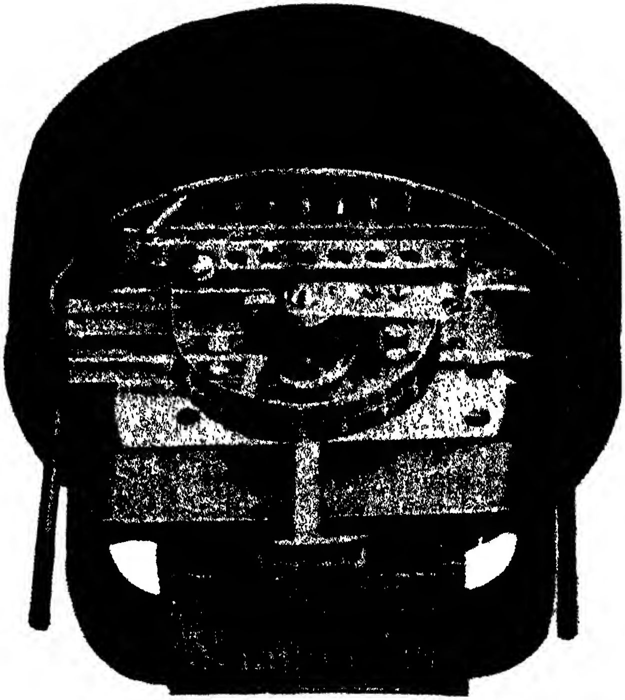


FIG. 4,197.—Westinghouse (induction) over current relay with cover removed showing ...

Definite Time.—A third protective principle which is of great value is the *definite time over current.* This principle is usually used in combination with the preceding one to give the familiar inverse definite minimum time relay.

Protective devices operating on this principle have inverse time characteristics up to a certain value of current, while at all higher values they operate in a certain definite minimum time. Such schemes are necessary

where there is no branching of the circuit at the junction of the faulty section to the rest of the system, as in a radial or a tandem system.

In applying this principle, the protective devices at the different points have their definite minimum times adjusted so that with abnormal values of current they operate in a definite order, beginning with the ones farthest from the generating station.

Directional.—Relays working on this principle *permit a normal direction of current only.**

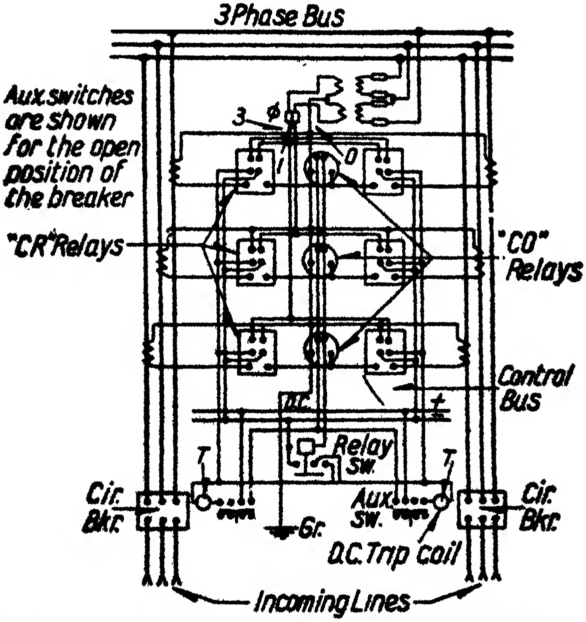
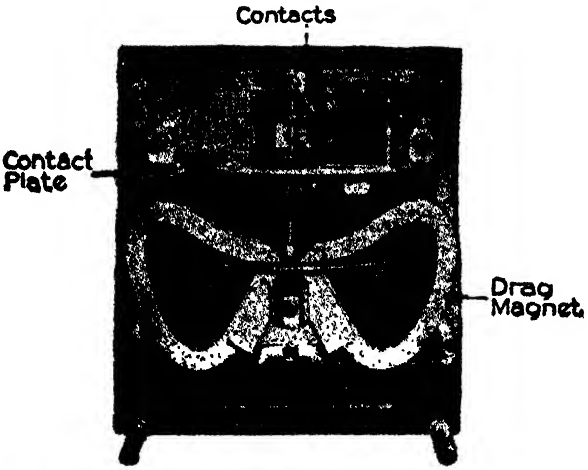
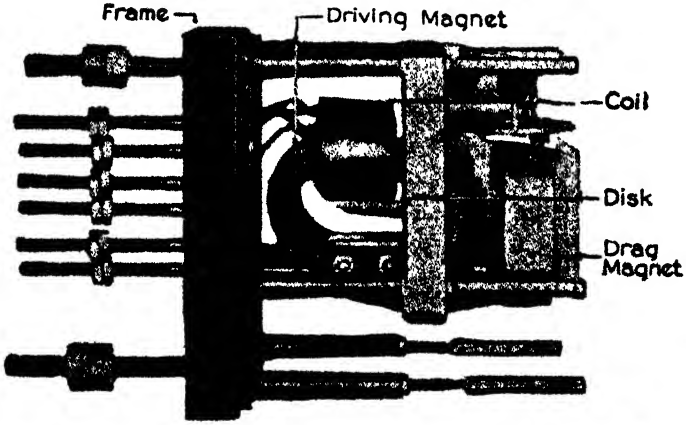


FIG. 4,198.—Westinghouse induction type directional relays protecting two incoming lines and induction overload relays arranged to open both breakers in case of trouble on the bus bars.

Differential.—In any section of a system *the current flowing into the section* **must equal** *that flowing out so long as the section*

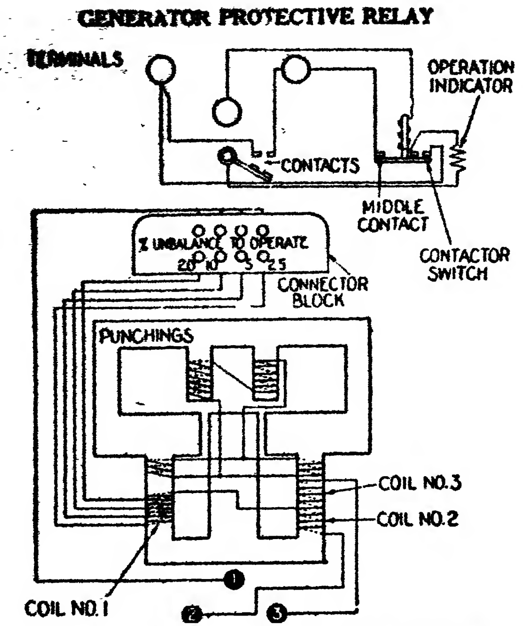
*NOTE.—*Direction of current* in an a.c. system means the *vector relationship between voltage and current.* Hence, to apply the reverse current principle, voltage must be introduced as the base of reference. It has been suggested to use as a reference a current whose direction is fixed, such as the fault current in a ground neutral. This scheme is not used very extensively, voltage is ordinarily the standard reference. Since under abnormal conditions the voltage may fall to a very low value, it is necessary to make the directional element very sensitive.

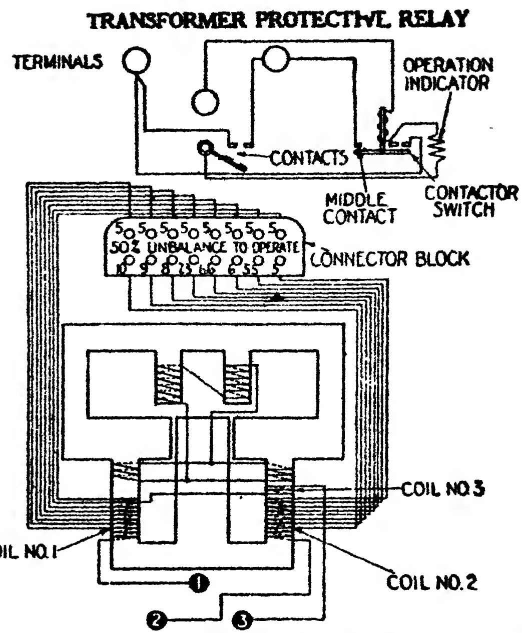




FIGS. 4,199 and 4,200. —Views showing construction of General Electric induction single element differential relay.

NOTE.—*There are two classes of directional relays:* the ordinary or *uni-directional* and the *duo-directional*. The uni-directional relays are intended to be installed on each separate feeder, whereas the duo-directional relay is to be connected between a pair of incoming lines at the substation end. The current transformers on the two lines are cross connected, so that the relay will trip whichever line is carrying the greater current away from the bus bars. The advantage of this arrangement over the use of the uni-directional relays is that one set of duo-directional relays costs less than two sets of the ordinary type. However, part of this advantage is lost because of the extra trouble and expense of making the cross connection. The duo-directional relay has been used on tie lines between generating stations where the balanced feature was important, but the selective differential relay is more suitable for this purpose. The duo-directional relay and the cross-connected scheme is not recommended for ordinary application. This relay is an excess current relay element, with its contacts in series with those of a selective watt meter; or directional element. The excess current element closes its contacts on excessive current in either direction, but the contacts of the selective watt meter element remain open as long as power flows into the station. Each relay has three separate adjustments: 1, the current at which it will operate; 2, the time in which it will operate, and 3, the direction in which the power must flow to operate it. It should always be connected to the circuit in such a way that it will trip its circuit breaker when the power is flowing away from the bus bars. The term "reverse power relay" is somewhat misleading while "directional relay" is nearer correct and preferred.





FIGS. 4,201 to 4,204.—Westinghouse ratio differential relays. *In operation,* in order to secure the ratio feature, both secondary currents to be balanced, as well as the differential current, are used in the relays. The currents in the two sum coils (the coils connected to terminals No. 2 and No. 3) produce an opening torque proportional to the sum or difference of the two secondary currents. The current in the difference coil (the coil connected to terminal No. 1) produces a closing torque proportional to the difference of the two secondary currents when the currents in the two sum coils are flowing in the same direction. Under normal conditions current passes through the current transformers, through coils No. 2 and No. 3 in series, and back to the current transformers. The currents in the sum coils are additive and produce an opening torque. When the secondary currents from the current transformers become unbalanced due to an internal fault in the protected apparatus, or for any other reason, the differential current must pass through coil No. 1 to the common junction of the current transformer secondaries. Thus an inequality of secondary currents results in unequal currents flowing in coils No. 2 and No. 3, and when these currents are in the same direction, the differential current flows through coil No. 1. When the secondary currents in the current transformers, or in the sum coils, are in opposite directions or bucking, the relay operates on a constant current in the difference coil (coil No. 1). The value of this current depends upon the tap setting of the relay.

has no electrical fault within itself. The device for detecting abnormal conditions is arranged to balance the normal input current or power against the normal output; it operates when any abnormal condition such as a short circuit or ground produces an unbalance.

The transient current of transformers, or the power loss within the section, acts in the same way as a fault, but of course to a much lesser degree; and these normal unbalances can be taken care of by the relay setting. A

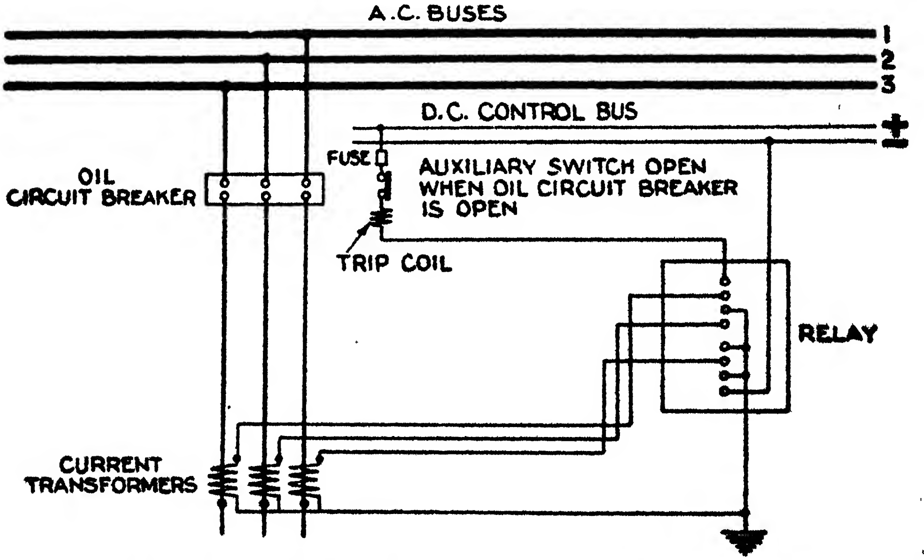


FIG. 4,205.—Wiring diagram showing application of General Electric induction differential relay for protection against phase unbalance of a three phase line.

protective scheme operating on this principle and applied to each individual piece of apparatus or section of the line, therefore disconnects the faulty section, but is inoperative under normal conditions and when faults occur in other sections of the system. It does not detect faults that draw no current (such as an open circuit, or a ground on an ungrounded system) and it must be set high enough to be inoperative on power losses or charging current within the section at abnormal current values caused by external faults.

Difficulties arise in the practical application of this scheme, because quite often current transformers must be able to maintain a balance all the way from partial load to perhaps twenty times full load. Trouble is also caused by unequal burdens placed on the current transformers by the leads and

other loads, and by improper impedance of the relay used to detect an unbalance.

Ground or Residual.—In numerous cases it is possible to use the magnitude of the ground current present in a system, as an indication of the presence or absence of abnormal conditions

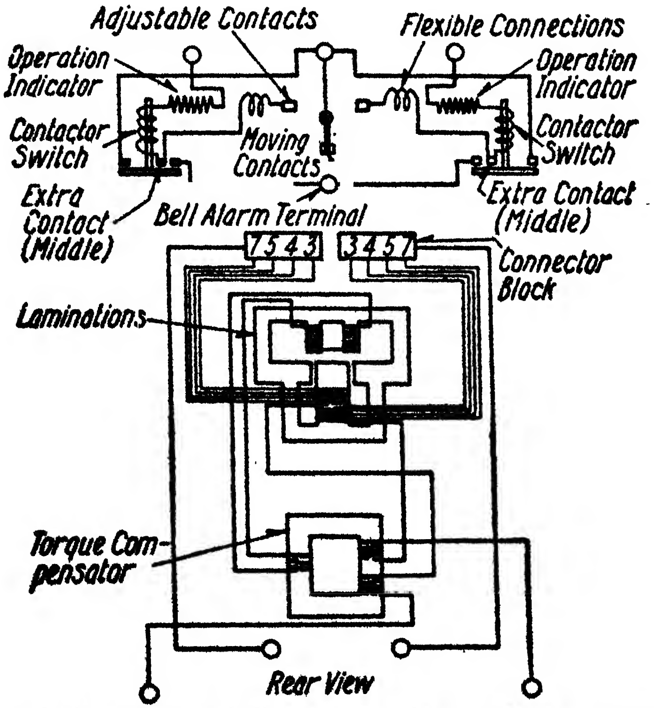


FIG. 4,206.—Internal connections of Westinghouse selective differential current relay. This relay is intended for short circuit and ground protection of parallel lines. It operates on current alone. *It has* two overload elements acting upon a common disc through a common magnetic circuit. Each element is connected separately to its own current transformer in corresponding phases of two balanced lines. The two elements are electrically opposed and under a condition of balanced line loads the fluxes in the magnetic circuit of the relay are equal and opposite giving a resultant zero torque on the relay disc. Under these conditions the disc which carries the moving contact is held in a middle position by the control springs. These springs are initially restrained in the zero position which prevents the disc making any movement until a predetermined current unbalance exists between the two lines. Under the proper conditions of current unbalance, the disc can rotate 80° in either direction from zero and make contact on either side. Thus the moving contact acts as a single pole double throw switch in the trip circuits of the circuit breakers of the two balanced lines, and will trip out the circuit breaker on the line carrying the heavier load. This action is the same regardless of the relative directions of the currents in the two lines.

on the system. With systems normally grounded at one point only, the existence of a current to ground is an indication of an abnormal condition.

This ground current may be detected directly, or as the difference from zero of the vectorial sum of the line currents at any point (this current is called the "residual current"). Complete protection is never obtained in this way, since these schemes are not sensitive to short circuits between phases.

Over Current with Under Voltage.—According to this prin-

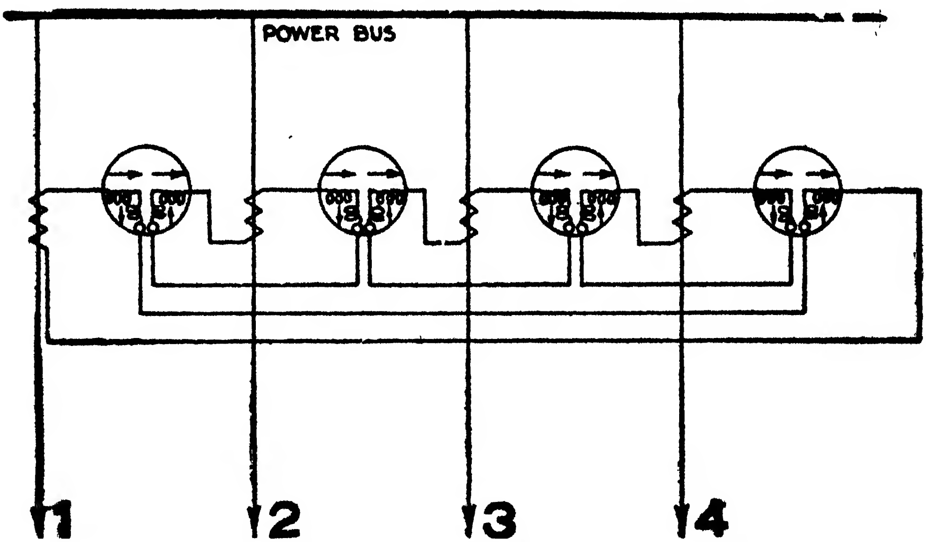


FIG. 4,207.—Westinghouse selective differential relays applied to four parallel feeders. Only one phase is shown. The arrows indicate instantaneous directions of the current under normal line conditions.

ciple, when there are short circuit conditions, *the voltage at points close to the fault is very low when the current is very high, while the voltage is progressively higher and the current is substantially the same at points nearer the generating station.* The protective device using this principle is essentially an over

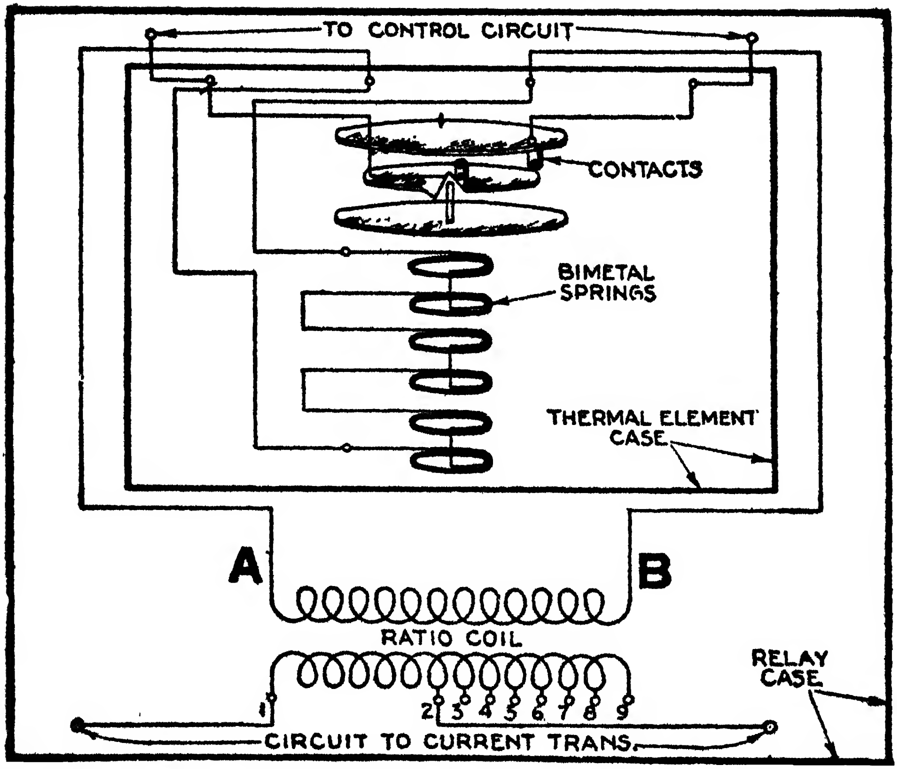


FIG. 4,208.—Diagram of internal connections of Westinghouse thermal overload relay, 60 cycle. The active element in the relay is made up of bimetallic springs which are connected either by means of suitable shunts or current transformers so as to receive a current proportional to the load current. The inner end of each spiral spring is fastened to a common shaft which is pivoted at each end. Due to the heating effect of the current as it flows through the bimetal springs a deflection results which causes the shaft to rotate. Near the top of the shaft is mounted an indicating dial carrying the moving contact. The stationary contact is mounted on the upper indicating dial. The position of this dial and contact can be changed by moving the time lever on top of the case of the thermal element and in this way it is possible to adjust the time of operation of the relay with a given current flowing through the bimetal springs. A glass window in the case makes it possible to see the dials for setting the position of the stationary contact, and observing the temperature indication of the lower dial. The position of the lower dial and the moving contact is dependent upon the temperature of the bimetal springs, while the position of the upper dial and stationary contact is determined by the setting of the time lever. The dials are divided into eight equal parts. The numbers 0 to 8 are arbitrary markings and are used for reference in setting the time delay. The trip circuit of the relay is closed when the same numbers on both dials are approximately in line. *For example*, in case of a circuit closing relay whose contacts are normally open, if number 7 of the upper dial be placed under the hair line of the glass window the contacts will close when number 7 of the lower dial comes under the hair line. The relative position of the two dials, therefore, determines the time delay before the trip circuit is operated for a definite load condition.

current inverse time device in which the time setting is automatically adjusted to be proportional to the voltage, so that the lower the voltage the lower is the time setting. Therefore, the ends of the faulty section nearest the short circuit clear in the minimum time, while the time settings at all other points on the system automatically assume higher values. This principle is usually combined with the directional principle.

Thermal.—Relays acting on this principle depend not on the value or duration of the current, but on the *rise of temperature due to an abnormal condition.*

The thermal principle does not give complete protection, but must be combined with short circuit protection.

Classification of Relays.—In all electrical installations protection of apparatus is important, but in some large central stations this is secondary to continuity of service.

To combine maximum protection without interruptions of service is not always possible, but these requirements can be approximated very closely by the use of reliable and simple controlling or protecting devices if proper care be taken to select the relays suited to the special conditions of the installation. To do this intelligently, a knowledge of the principles just given and the various types of relays developed to embody one or more of these principles is necessary.

There is a multiplicity of types and a classification to be comprehensive, should, as in numerous other cases, be made from several points of view. Accordingly relays may be classified:

1. With respect to the nature of the service performed, as

a. Protective;
b. Regulative;
c. Communicative.

2. With respect to the operating current, as

a. Alternating current;
b. Direct current.

3. With respect to the manner of performing their function, as

a. Circuit opening;
b. Circuit closing.

4. With respect to the operating current circuit, as

a. Primary;
b. Secondary.

5. With respect to the abnormal conditions which caused them to operate, as

a. Overload;
b. Underload;
c. Over voltage;
d. Low voltage;
e. Reverse energy;
f. Reverse phase.

6. With respect to the time consumed in performing their function, as

a. Instantaneous (so-called);
b. Definite time limit;
c. Inverse time limit.

7. With respect to the character of its action, as

a. Selective;
b. Differential.

8. With respect to whether it act directly or indirectly on the circuit breaker, as

a. Main;
b. Auxiliary.

Protective Relays.—These are used to protect circuits from abnormal conditions of voltage, or current, which would be undersirable or dangerous to the circuit and apparatus contained therein.

Ques. How do protective relays operate?

Ans. They act in combination with automatic circuit breakers, operating when their predetermined setting has been reached, energizing the trip coil of the circuit breaker and opening the circuit.

Regulating Relays.—This class of relay is used to control the condition of a main circuit through control devices operated by a secondary circuit.

Ques. For what service are relays of this class employed?

Ans. They are used as feeder circuit or generator regulators.

Ques. How do they differ from protective relays?

Ans. They have differentially arranged contacts, that is to say, arranged for contact on either side of a central or normal position.

Communicative Relays.—These are used for signalling in a great variety of ways for indicating the position of switching apparatus or pre-determining the condition of electric circuits.

A.C. and D.C. Relays.—As nere used, the classification refers to the kind of current used on the auxiliary circuit. In some cases direct current is used to energize the trip gear of the circuit breaker or oil switch, and in others, alternating current.

A.c. and *d.c.* relays are respectively known as *circuit opening* and *circuit closing* relays, being later fully described.

Circuit Opening Relays.—The duty of a circuit opening relay is *to open the* **auxiliary circuit,** *usually alternating current, and thereby cause the oil switch or circuit breaker to be opened by the use of a trip coil in the secondary of a current transformer, or by low voltage release coil.*

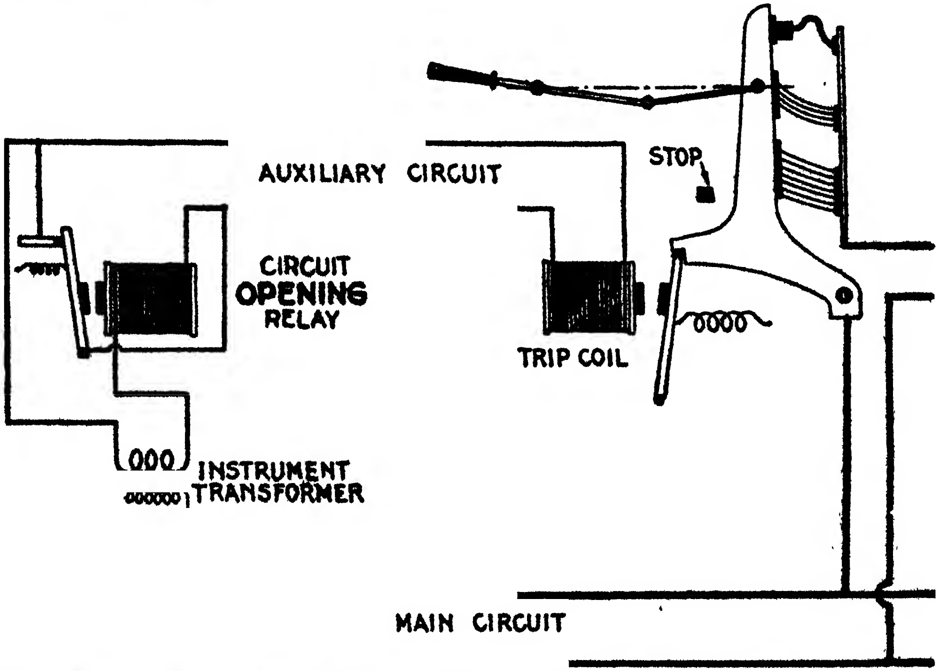


FIG. 4,209.—Diagram illustrating the operation of a *circuit opening relay.* When the relay contacts are in the normal closed position, as shown, the coil is short circuited. When the predetermined abnormal condition is reached in the main circuit, the relay contacts are opened with a quick break, sending the current through the trip coil momentarily, and opening the breaker.

The trip coil of the breaker is generally shunted by the relay contacts and when the moving contact of the relay disengages from the stationary contact, the current from the transformer which supplies the relay, flows through the trip coil thus opening the breaker. These features of operation are shown in fig. 4,209.

Ques. Where are circuit opening relays chiefly employed?

Ans. In places where direct current is not available for energizing the trip coil.

Ques. What is the objection to alternating current trip coils?

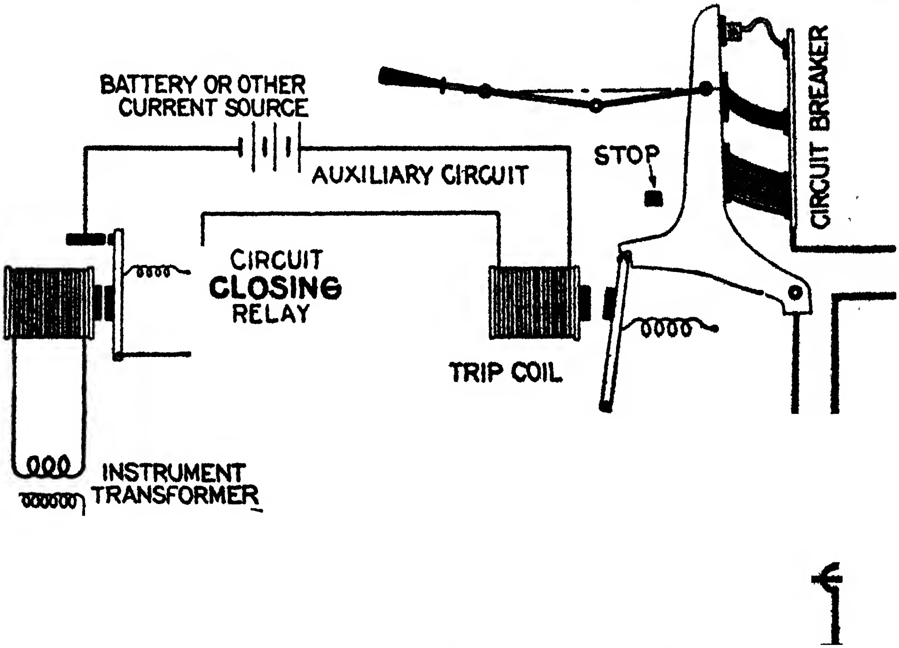


FIG. 4,210.—Diagram illustrating the operation of a *circuit closing relay*. When the predetermined abnormal condition is reached in the main circuit, the relay closes the auxiliary circuit, thus energizing the trip coil and opening the breaker.

Ans. They have relatively high impedance and impose a heavy volt ampere load on the transformers.

Circuit Closing Relays.—The duty of a circuit closing relay is to close the auxiliary circuit at the time when the predetermined abnormal condition is reached in the primary circuit. The closing of the auxiliary circuit energizes the trip coil and opens the breaker.

Fig. 4,210 shows the operation of a circuit closing relay. When the current or pressure in the main circuit reaches the predetermined value at which the protective system should operate, the relay magnet attracts the pivoted contact arm and closes the auxiliary circuit; this permits current to flow from the current source in that circuit and energize the trip coil thus opening the main circuit.

Ques. What kind of current is generally used for the auxiliary circuit of a circuit closing relay?

Ans. Direct current.

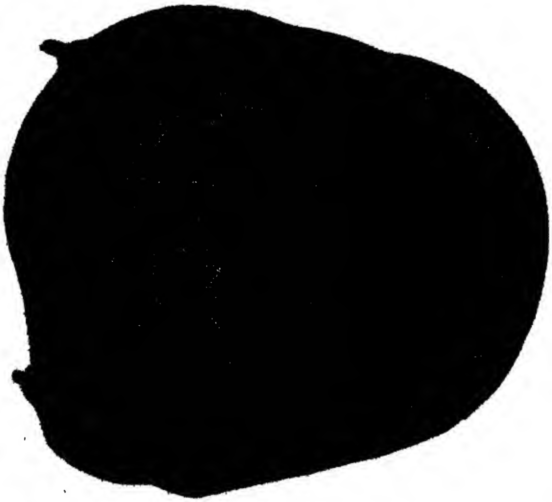


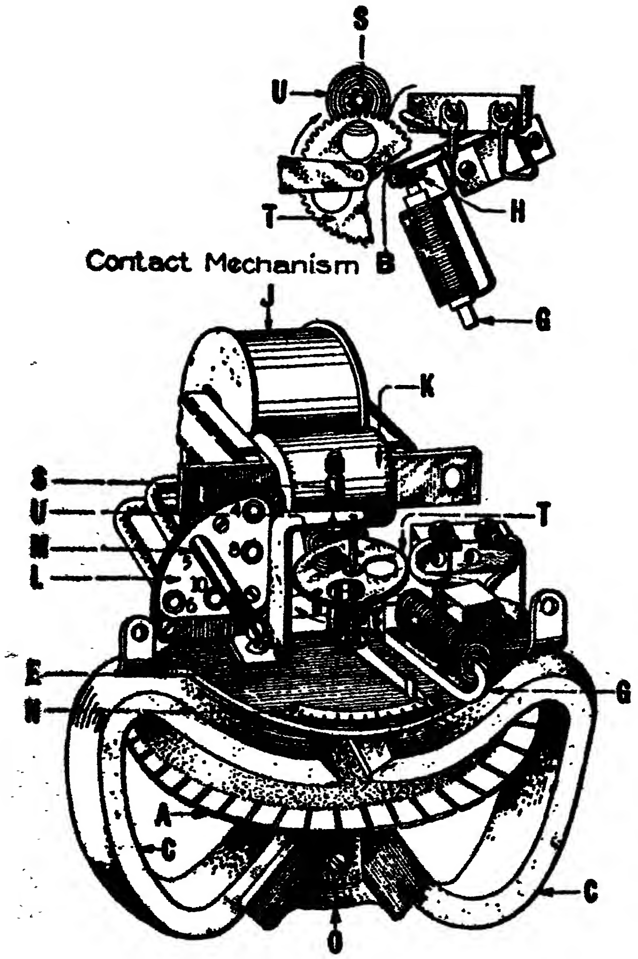
FIG. 4,211.—General Electric single pole induction overload relay. *The principles of operation* are similar to those of induction meters. These relays are *circuit closing* and operate with a time relay which is inverse at low current values and which approaches a definite time at high current values. *In operation*, the holding magnet keeps the contact closed until circuit breaker opens. The trip circuit must be opened by a separate auxiliary switch.

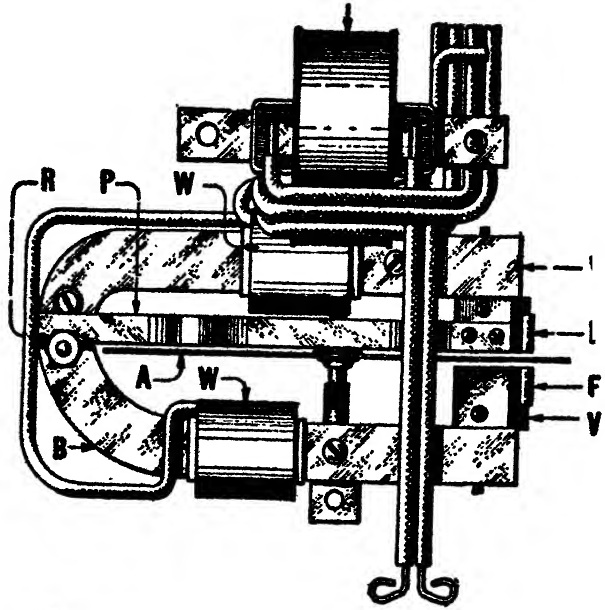
Ques. At what pressure?

Ans. From 125 to 250 volts.

Ques. Where is this current usually obtained?

Ans. From a storage battery, or from the exciter.





A Disc
B Driving magnet.
C Retarding permanent magnet
D Contacts
E Time setting lever
F Shading coils
G Holding magnet
H Armature
J Saturating transformer primary
K Saturating transformer secondary
L Current tap plate
M Current tap plug
N Time lever scale
O Magnet shoe
P Temperature compensating strip
R Temperature compensating screw
S Pinion
T Contact gear.
U Spring
V Upper and lower pole pieces
W Magnet coils

FIGS. 4,212 to 4,214.—Views showing mechanism of General Electric single pole induction overload relay.

Ques. For what current are the contacts ordinarily designed?

Ans. About 10 amperes.

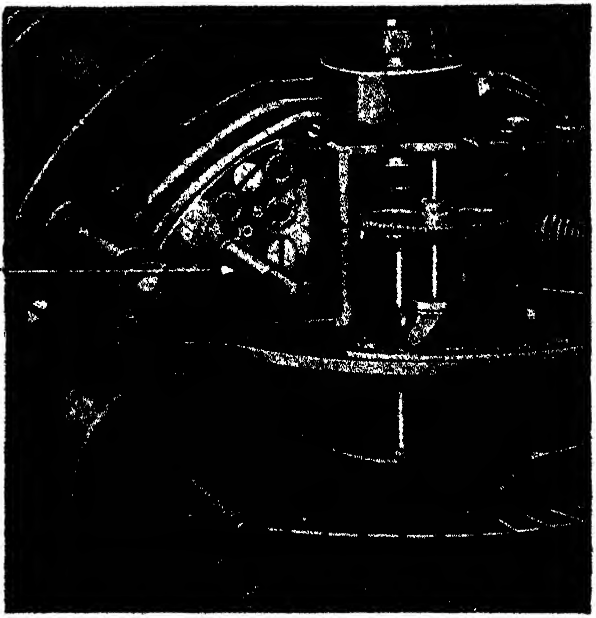
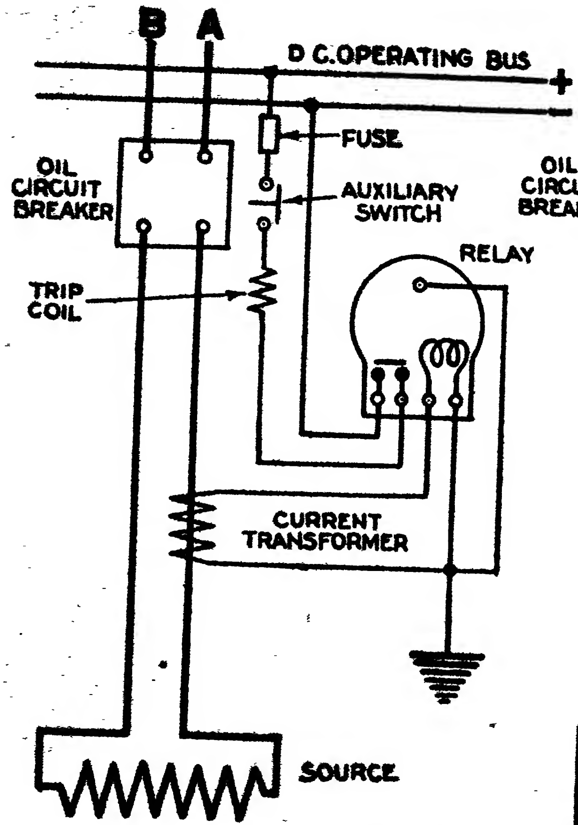


FIG. 4,215.—Current tap plate of General Electric single pole induction overload relay. The primary winding of the saturating transformer is provided with taps for different current settings. Connection for any tap is made by means of a tap plug which is screwed into the terminal of the tap until its shoulder bears against the face of the tap plate. This plate is permanently connected to one of the current studs of the relay, and is numbered for the identification of the taps. The numerals 4, 5, 6, 8, and 10 represent the minimum current in amperes that each tap requires to cause the relay to close its contacts. The ampere rating of the tap used should approximately equal the secondary current which corresponds to the normal "full load" current of the line or machine to be protected.

NOTE.—*Operation of induction overload relays.* See figs. 4,212 to 4,214. When an overload occurs, the rotation of the disc, actuated by a "U" shaped driving magnet and retarded by a pair of permanent magnets, causes the contact tips to be forced together after an interval of time, which is dependent upon the current, also the starting position of the disc as predetermined by the setting of the time lever. The driving torque is generated by the phase splitting action of shading coils on the pole faces. The coil of the holding magnet is connected in series with the tripping contacts, causing this magnet to be energized at the instant the contacts close, and to attract and firmly hold an armature secured to one of the contact members. This holds the contact firmly closed until the tripping current is interrupted by a circuit opening auxiliary switch on the circuit breaker, thus preventing flashing or burning of the contact surfaces.



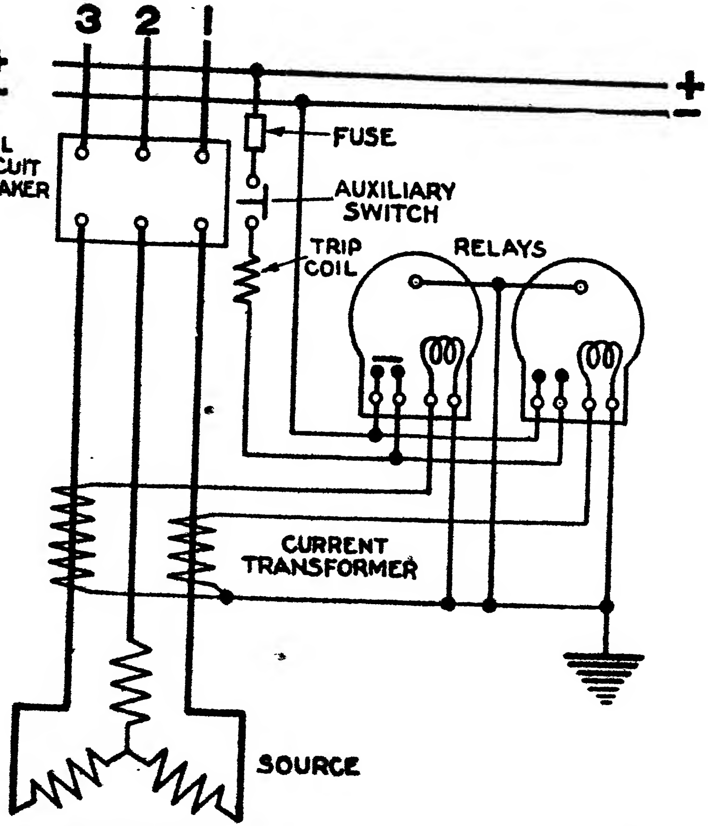


FIG. 4,216.—Connections for single phase circuit with General Electric induction overload relay. Auxiliary switch open when oil circuit breaker is open.

FIG. 4,217.—Connections for three phase, three wire circuit with General Electric induction overload relay, using two current transformers. Auxiliary switch open when oil circuit breaker is open.

Primary and Secondary Relays.—Primary relays are sometimes called series relays as they have the current coils connected directly in series with the line, both on high and low tension circuits.

Secondary relays receive their current supply from the secondary circuits of current transformers. Alternating current relays connected to secondary of pressure transformers and relays with both current and pressure windings are included in this class.

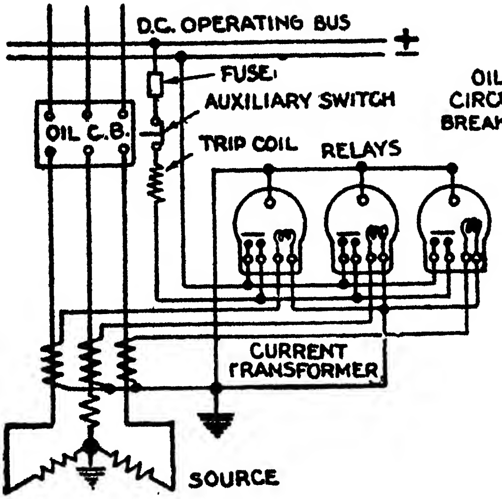
Secondary relays are more accessible and more easily adjusted than primary relays, as they are always at low voltage, which makes it possible to change the calibration or even the coils without the necessity of shutting down the lines, regardless of their voltage. Such relays are subjected to secondary load conditions only; consequently, the mechanical construction does not receive the heavy service that series relays are subject to, and, therefore, a greater degree of refinement and more accurate characteristics are obtainable. For these reasons, secondary relays are used for the majority of conditions that require the automatic tripping of oil switches. The secondary relays operated by current are connected to the secondary circuits of current transformers and in operating the contacts are either instantaneous or time limit. The latter are used extensively to obtain selective opening of circuits in a pre-determined sequence.

Ques. What is the usual winding of the coils?

Ans. The current coils are usually wound for 5 amperes and the pressure coils for 110 volts.

Overload Relays.—Series relays are connected directly in series with the line and are chiefly used with high pressure oil break switches for overload protection. If current transformers are to be used on the same circuits for other purposes, and have sufficient capacity to admit of adding a relay coil, secondary relays would be more economical; otherwise, the series relays are less expensive.

By means of a specially treated wooden rod, the relay operates a tripping switch, closing a separate tripping circuit, usually 125 or 250 volts direct



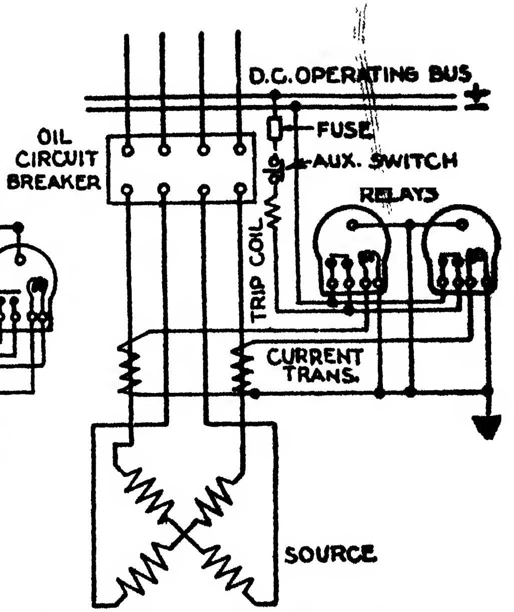


FIG. 4,218.—Connections for three phase, three wire circuit, neutral grounded with General Electric induction overload relay. Auxiliary switch open when oil circuit breaker is open. A circuit opening auxiliary switch which will be operated by the opening movement of the breaker to be tripped, must be connected in series with the relay contacts.

FIG. 4,219.—Connections for two phase, four wire circuit with General Electric induction overload relay Auxiliary switch open when oil circuit breaker is open.

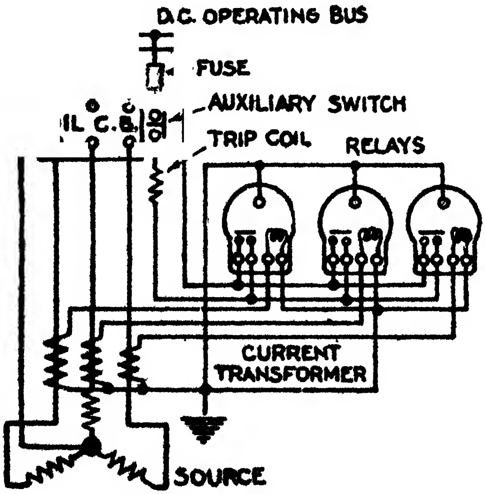


FIG. 4,220.—Connections for three phase, four wire circuit with General Electric induction overload relay. Auxiliary switch open when oil circuit breaker is open.

current. Series relays are essentially the same as secondary relays except in the coil winding and insulation.

Underload Relays.—These are similar in construction to low voltage relays but have current instead of pressure windings.

Over Voltage Relays.—These are usually of the circuit closing type and are similar to secondary overload relays, but have pressure instead of current windings.

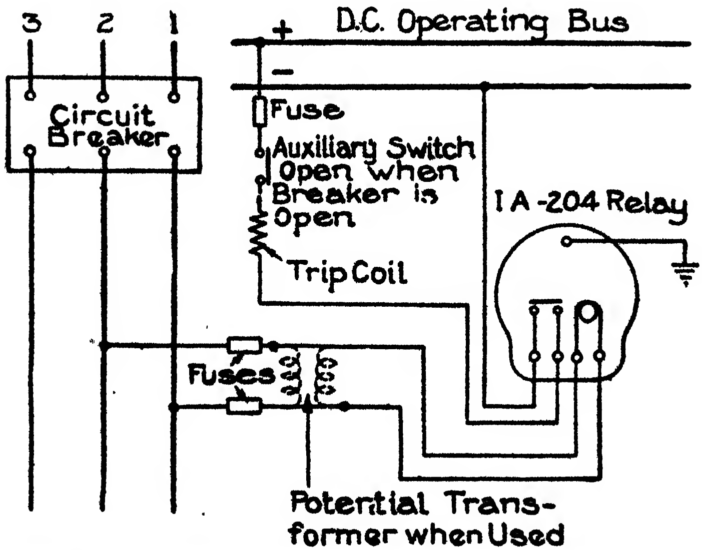


FIG. 4,221.—Connections of General Electric induction under voltage relay for protection of a three phase system.

Low Voltage Relays.—Relays of this class are in most cases used for the protection of motors in the event of a temporary weakening or failure of the pressure. They are also used in connection with a low voltage release or shunt trip coil on an oil switch or a circuit breaker.

Reverse Energy Relays.—The chief object of this species of relay is to protect the generator. When so used, the overload

adjustment is set at the maximum value to give overload protection only at the maximum carrying capacity of the generator and a sensitive reverse protection to prevent a return of energy from the line.

Reverse Phase Relays.—This type of relay is used chiefly

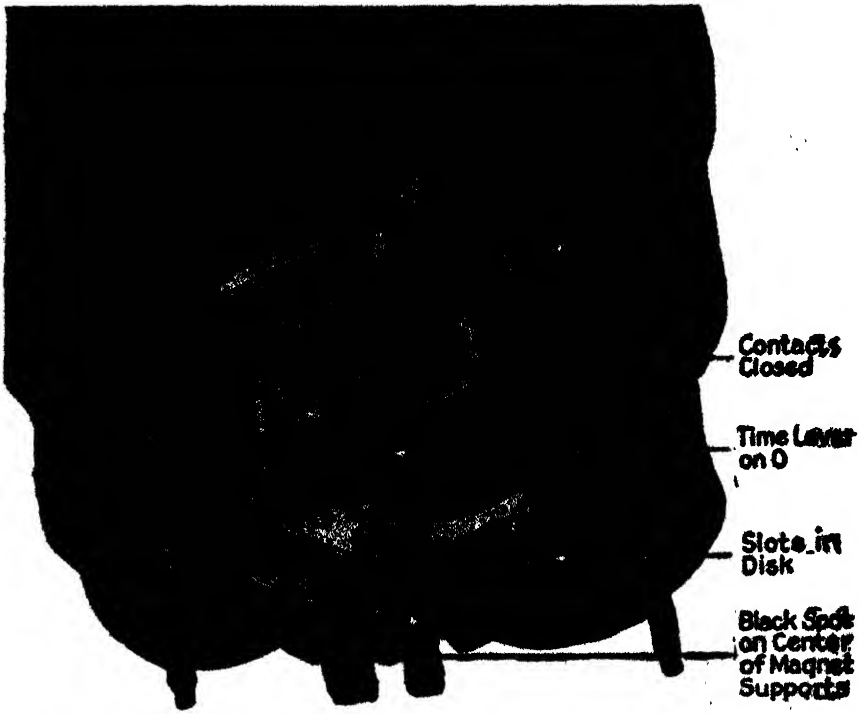


FIG. 4,222.—View of General Electric inductio rload relay showing relation of contact, time lever and black spot on disc. The time lever scale is adjusted so that when the time lever is set on zero the contacts are just closed. The contact springs are adjusted to give the contacts a separation of 6¾ in. when free. A black spot has been painted on the edge of each disc. The center of this mark should come exactly on the center line of the bracket supporting the permanent magnets when the time lever is set at zero.

NOTE.—Saturating transformer of General Electric induction overload relay. This device is mounted in the relay case. The primary winding is connected to the current studs of the relay and the secondary winding is connected directly in series with the coils on the "U" shaped magnet which drives the disc. At high currents the saturation characteristic limits the torque and produces approximately definite time action.

to prevent damage in case of reversal of leads in re-connecting wiring to two or three phase motors.

Time Element.—It is often inconvenient that a circuit breaker should be opened immediately on the occurrence of what may prove to be merely a momentary overload, so that time lag attachments are frequently provided, particularly with relays. These devices, which may form part of the relay or may be quite distinct from it, retard its action until the overload has lasted for a pre-determined time—several seconds or more.

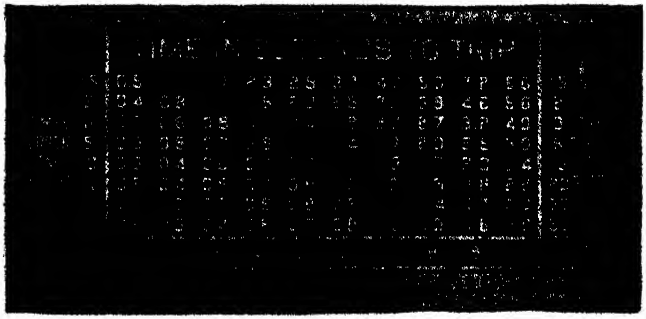


FIG. 4,223.—Time index plate of General Electric induction overload relay. Each of operation given on the index plate corresponds to some multiple of the mini g current for which the tap plug is set, and some position of the time lever (the "Times Current Tap Setting" at each end of the index plate refers to the adjacent of multiples, or numbers of times the current tap setting).

Ques. What should preferably govern the time lag?

Ans. It should depend on the extent to which the overload is reduced as the time elapses.

So Called Instantaneous Relays.—The so called instantaneous relays operate almost instantly on the occurrence of the abnormal condition that they are to control.

There is of course a slight time element comparable with that of an overload circuit breaker, but for practical purposes, the operation may be considered as instantaneous.

Time Limit Relays.—Under this classification there are two sub-divisions.

1. Definite time limit;
2. Inverse time limit.

Ques. Describe the time mechanism of a definite time limit relay.

Ans. It consists of an air dash pot, and an air diaphragm or equivalent retarding device connected to the contact mechanism.

Ques. How does it operate?

Ans. In some designs, when the contacts are released, they descend by gravity against the action of the retarding device thereby making contact a definite interval after the occurrence of the abnormal condition.

Ques. How does the inverse time limit type operate?

Ans. The actuating and contact mechanism is attached directly to an air bellows and in operation tends to compress the bellows against the action of a specially constructed escape valve in the latter.

Ques. Why is the arrangement called *inverse* time limit?

Ans. Because the retardation varies inversely with the pressure on the bellows, and therefore inversely with the magnitude of the abnormal condition.

Ques. What other device may be used to retard the operation?

Ans. A damping magnet is sometimes used which acts on a disc or drum and which may be adjustable.

Ques. How is the inverse time element introduced by this arrangement?

Ans. The retardation is due to eddy currents induced by moving the disc or drum through the magnetic field. The reaction thus induced varies inversely with the magnitude of the force with which the disc or drum is urged through the field and hence inversely with the abnormal condition.

Ques. What are the ordinary limits of adjustment for inverse time limit relays?

Ans. From one-half second to 30 seconds, depending upon the time setting and magnitude of the overload current.

A setting of from two to six seconds is ordinarily used, depending upon the requirements. Where selective operation is desired a minimum setting of two seconds is recommended.

Differential Relays.—In this type of relay there are two electromagnets. In normal working these oppose and neutralize each other. Should, however, either winding become stronger or weaker than the other, the balance is upset, the magnet energized, and the relay comes into operation.

A modification of such a relay for alternating current is shown in fig. 4,233. Assume that the circuit A, has the larger pressure induced in it, whereas, should the main current reverse with reference to the shunt current, the circuit B, would have the larger induced pressure.

Impedance or Distance Type Relay.—This relay is of the induction disc type, similar to the ordinary over current type relay, but with the addition of a voltage restraining coil which is connected mechanically to the disc and to the contact mechanism. Fig, 4,224 shows an impedance relay of the non-directional type with the cover removed.

The disc is rotated whenever the current in the current coil exceeds a definite value and is damped by the permanent magnets in such a manner

FIG. 4,224.—Westinghouse non-directional impedance relay with cover removed.

that its speed is approximately proportional to the magnitude of the current. Instead of operating the contacts directly, the movement of the disc winds up a spring, one end of which is fastened to a shaft that is geared to the disc shaft. The other end of the spring is connected by means of a lever to a rocker arm pivoted at its center and mounted directly above the disc. This rocker arm carries the contact on one end. The core of the restraining coil is suspended from the other end.

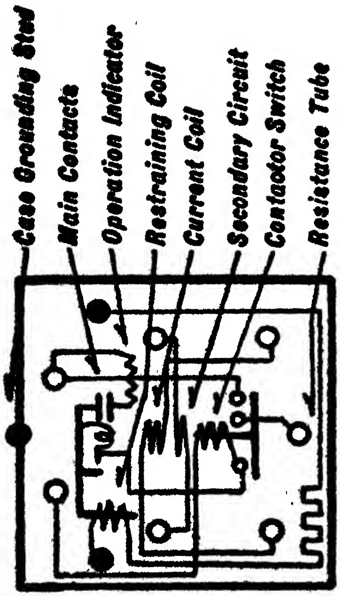


FIG. 4,226.—Internal connections of Westinghouse non-directional impedance relay.

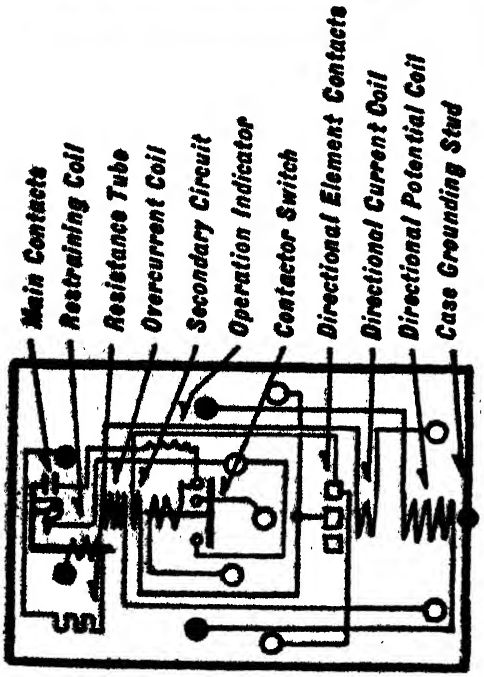


FIG. 4,225.—Internal connections of Wes... l impedance relay.

In operation, the pull of the voltage coil, which opposes the closing of the contacts is directly proportional to the voltage. It will be seen that for any given applied voltage, the spring must be wound up a definite amount before enough pull will be developed to overcome the pull of the voltage coil and close the contacts. The speed with which the spring is wound to this definite amount is dependent on the magnitude of the current. The time of operation, since it is directly proportional to the voltage and inversely proportional to the current, is proportional to the impedance or the distance from the fault. Thus, by properly setting the relays, discriminative action can be obtained by means of which the relay nearest the fault will operate and open its circuit breaker before any other relay on the other sections of lines will close its contacts.

Since in some cases a delta voltage may be reduced to zero without affecting the magnitude of the star voltages to any great extent, and vice versa, it is always necessary to use two relays per phase where line and ground protection are desired on a grounded system. One set of relays will be restrained by the delta voltages and one by the star volt-

This impedance relay may be combined with an ordinary directional watt element to give a directional impedance relay which will trip its breaker only when the power flow is in the predetermined direction.

Induction (Instrument Type) Inverse Time Limit Relay.—The instrument type relay is not as rugged mechanically as the solenoid relay, and the contacts are not as heavy, although it affords instrument accuracy and gives satisfactory operating characteristics.

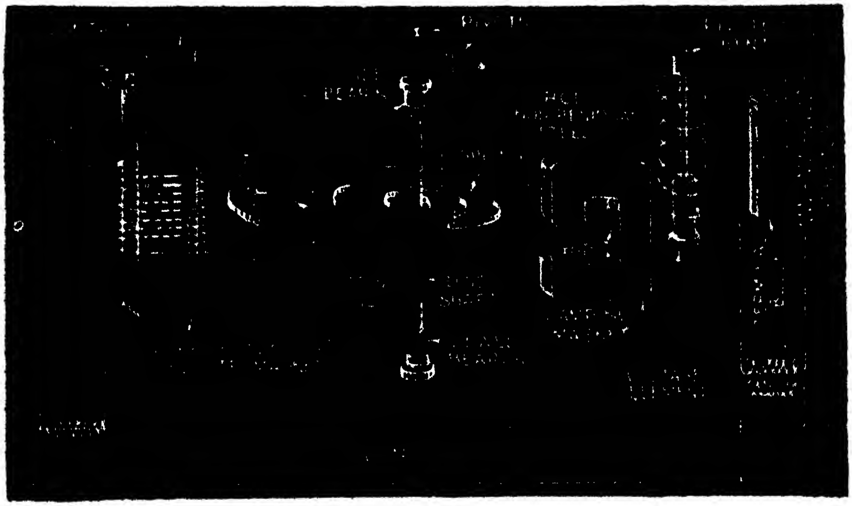


FIG. 4,227.—Pictorial diagram of Westinghouse impedance (distance) relay. As usually applied this relay requires for its operation the use of current and voltage transformers. The current element tries to close its contacts in a time varying inversely as the current whereas the voltage coil holds them open for a time varying directly as the voltage. Stated mathematically

$$T = \frac{E}{I} \text{ but } \frac{E}{I} = Z = \text{impedance} = \text{distance.}$$

Stated in non-mathematical language, the time of operation of this relay varies as the distance of the short circuit from the relay. This applies not only to "dead" but also to "high resistance" short circuits, assuming that the latter be possible.

If the tripping current be too heavy for the relay contacts, they may be connected to a tripping relay that is instantaneous and requires only a small amount of current to operate.

The time delay is obtained by a specially designed *rotating induction* disc similar to that used in watt meters.

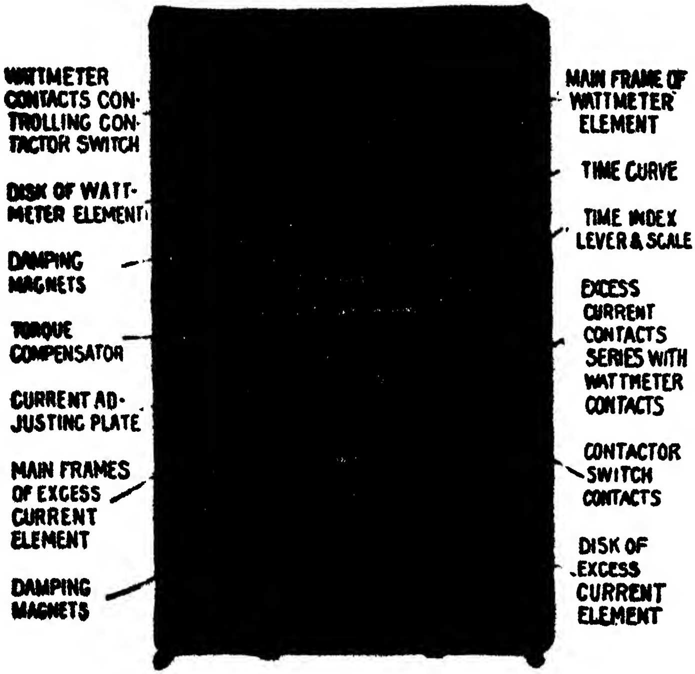


FIG. 4,228.—Westinghouse induction type relay with adjustable definite minimum inverse time element. This is a reverse power (power directional) relay.

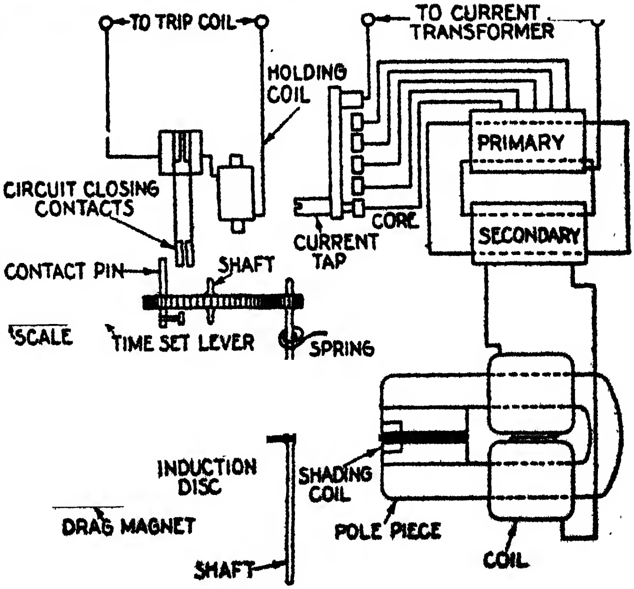


FIG. 4,229.—Mechanism of overload induction type

As shown in fig. 4,229 the movement of a contact pin on a gear closes the contacts. The current calibration is obtained by using different taps in the current coil, and in this way controlling the speed of the disc. The time calibration is obtained by adjusting the distance through which the disc travels before contact is made.

***How to Select Relays.**—The following general information

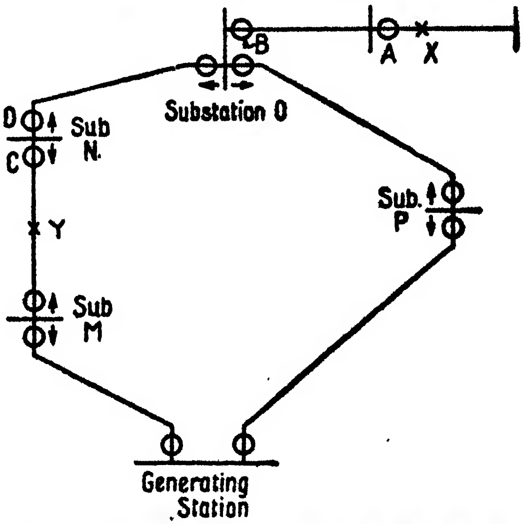


FIG. 4,230.—Diagram of transmission system illustrating the use of impedance (distance) relays. The conditions most difficult for proper discrimination in the time element are those encountered by relay A and B, when a short circuit occurs at the point X. Since both A and B, have the same current flowing through them, the increased time element required by B, can only be obtained by the increase in voltage at B, above that at A. The impedance relay is so designed that, if with the minimum possible short circuit current which can flow to X, there is a difference of 5% in the voltage between A and B, proper discrimination will be obtained. For heavier short circuit where the drop in voltage will be more than 5% the action of the relays can be made much quicker and more reliable. *In other words*, the only limitation on the application of the impedance relay is that the sub-stations or the switching stations must not be too close together. Another condition which must be met is that which is due to a short circuit at Y, in the diagram. Under such a condition the relay at C, in sub-station N, should of course operate, but the voltage and current conditions will be exactly the same on both relays C and D. Therefore, in order to prevent the relay D, operating, it is necessary to equip it with a device similar to a check valve which will prevent it operating whenever power is flowing into the sub-station. This device is known as the directional element and consists of a contact making watt meter with its contact in series with the main contact of the relay. This principle is the same as that employed in the impedance relay. In the diagram the arrow shows where directional relays are required and also indicates by the same symbol, the direction in which they will operate when trouble occurs.

*NOTE.—As suggested by the General Electric Co

on relays, will be of interest and assistance in making a selection from the various relays previously described to meet the requirements of modern power house and sub-station layouts.

Single pole relays are used on single phase and on balanced three phase circuits.

Double pole relays are used on ungrounded three phase and on quarter phase.

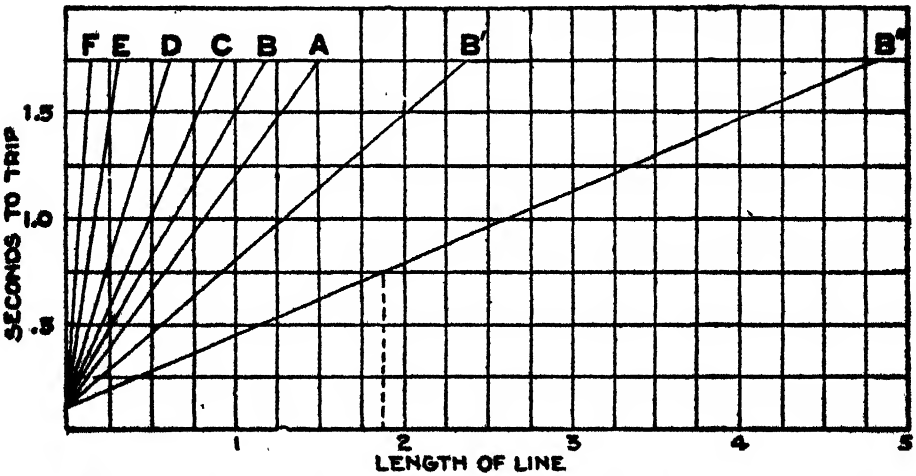


FIG. 4,231.—Time distance curves for impedance relays. ***Example:*** If in fig. 4,230 trouble should occur at X, the relay at A, should operate in say .1 second. The circuit breaker will require about .25 second to open, the total time required to clear the short being .35 second. Now the relay at B, should have sufficient time delay so that it will not close its contacts before the breaker at A, has had a chance to open (.35 second). If this time be doubled in order to allow an ample margin of safety, a reasonable setting for the relay at B, is then obtained. Therefore, the dash line across the diagram is drawn to indicate the time which should be required to operate any relay. This is the extreme case; short circuit will be cleared in considerably less time. This difference in time adjacent stations is of course due to the difference in voltage between them. With the present design of relay the difference in voltage between two consecutive stations carrying the same trouble current must be at least 5% in order to secure proper discrimination.

Triple pole relays are used on three phase grounded neutral and interconnected quarter phase.

Circuit closing relays are recommended in all cases where a constant source of direct current is available for operating trip coils.

Considering first alternating current circuits, the prevailing practice is to make the circuit breakers by which the alternators are connected to the low tension bus *non-automatic*, in order to insure minimum interruption of alternator service. The chance of trouble in this part of the circuit is remote, but should it occur, the station attendant could generally open the circuit breaker before the machines are injured.

Reverse current relays of instantaneous or time limit types are often connected to the secondaries of current and of pressure transformers to indicate by lamp or bell any trouble that may occur in the generator circuit.

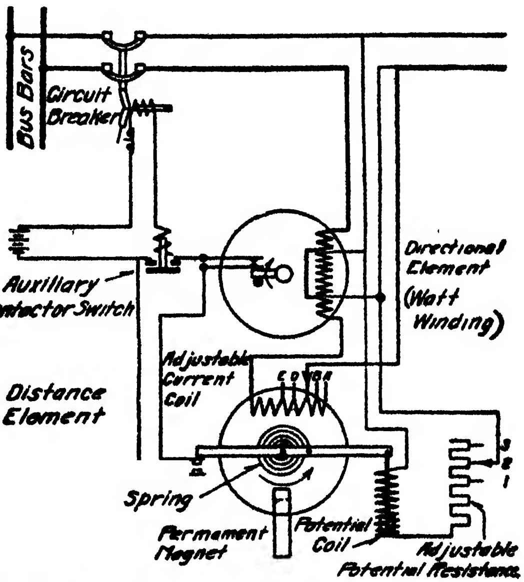


FIG. 4,232.—Diagram of Westinghouse impedance (distance) relay with directional element.

These relays operate with a low current reversal at full pressure and conversely with a proportionally greater current at voltages less than normal.

At zero pressure, the relay would act as an overload one, set for high overload.

At zero current, a voltage considerably in excess of normal would be required to operate it.

Specifications sometimes call for automatic generator circuit

breakers; in this case *definite time limit overload relays* are used. They are connected in the secondaries of current transformers and are designed to give the same time delay for all trouble conditions; they allow the defective circuit to be opened, if possible, at a point more remote from the alternator than the alternator circuit breaker.

When the total alternator capacity exceeds the rated rupturing capacity of the circuit breakers, one or more sectionalizing circuit breakers are placed in each bus.

If operating conditions admit, these devices are made non-automatic and are left disconnected except in case of emergency; but if it be necessary for them to be continually in service, they may be made automatic by *means of instantaneous overload relays* connected to current transformers in the low voltage bus; the relays being adjusted to trip the circuit breaker under short circuit conditions, confining the trouble to one section and preventing the circuit breakers rupturing more than their rated capacity.

Installations with but *one bank of power transformers*, and without a high voltage bus, are provided with automatic circuit breakers operated by an *inverse time limit relay*.

The relay is connected to the secondaries of current transformers, which in turn are connected in the low voltage side of the power transformer.

Stations with *more than one bank of power transformers*, a high voltage bus, and high and low voltage circuit breakers, may have both circuit breakers arranged to trip at the same time or one after the other. As in the former case, they are operated from the inverse time limit relay connected in the low voltage side.

In plants in which two or more banks of transformers operated in parallel between high and low voltage buses, it is desirable to have for each transformer bank, an automatic circuit breaker equipment which will act selectively and disconnect only the bank in which trouble may occur. With a circuit breaker on each side of the transformer bank, selective action may be secured in two ways as follows:

1. By means of an instantaneous differential relay connected in the secondaries of current transformers installed on both the high and low voltage sides of each transformer bank.

The relay operates on a low current, reversal on either side of the bank.

2. By means of one inverse time limit, secondary or series relay installed on that side of the transformer bank which is opposite the source of power, the relay being arranged to trip both the high and low voltage circuit breakers.

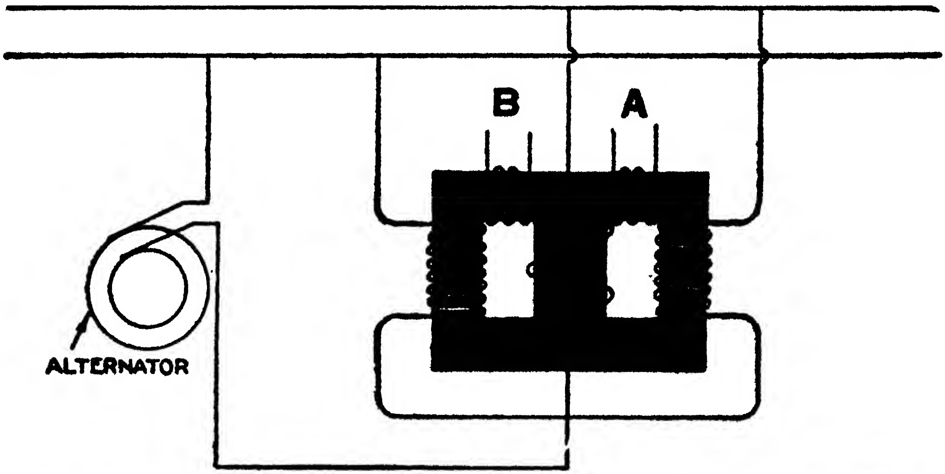


FIG. 4,233.—Differential relay transformer and reverse current circuit breaker discriminating device. A differential relay is *one whose electro-magnet has two windings. In normal working these oppose and neutralize one another.* Should, however, either winding become stronger or weaker than the other, the balance is upset, the magnet is energized, and the relay comes into operation. A modification of such a relay for alternating current is here shown, from which it will be seen that when the currents are as indicated, the circuit A, has the larger pressure induced in it, whereas, should the main current reverse with reference to the shunt current, the circuit B, would have the larger induced pressure.

The first method has the disadvantage of high first cost due to the high voltage current transformers required, but is more positive than the second method and is independent of the number of transformer banks in parallel.

The second method is the less expensive of the two and protects against overloads as well as short circuits in the transformers, but it is less positive and introduces delay in the disconnection of the transformer when trouble occurs. Furthermore, it is not selective when less than three banks are operating in parallel.

The automatic circuit breakers in the outgoing line may be operated from inverse time limit relays connected in the secondaries of current transformers; or in case transformers are not necessary for use with instruments, series high voltage inverse time limit relays connected directly on the line may be used.

Whether to select current transformers with relays insulated for low voltage, or to choose series relays, is a question of first cost and adaptability to service conditions. Below 33,000 volts, the commercial advantages in favor of the series relay are slight, and since it is somewhat difficult to design this device for the large current capacities met with at the lower voltage, it is generally the practice to use the relay with current transformer, because of its operating advantage. This practice, however, is not entirely followed, since some service conditions (described later) make the use of series relays very desirable and practical.

Inverse time limit relays are satisfactory for one, or more than two outgoing lines in parallel as they act selectively to disconnect the defective line only, but installations with only two outgoing lines in parallel have the same load conditions in both lines and selective tripping of the circuit breakers in the defective line is obtained by means of a selective relay acting without delay under short circuit conditions only.

The relay design and action is similar to the reverse current relay previously mentioned, and is connected to the secondaries of current transformers in each high voltage line and pressure transformers in the low voltage bus.

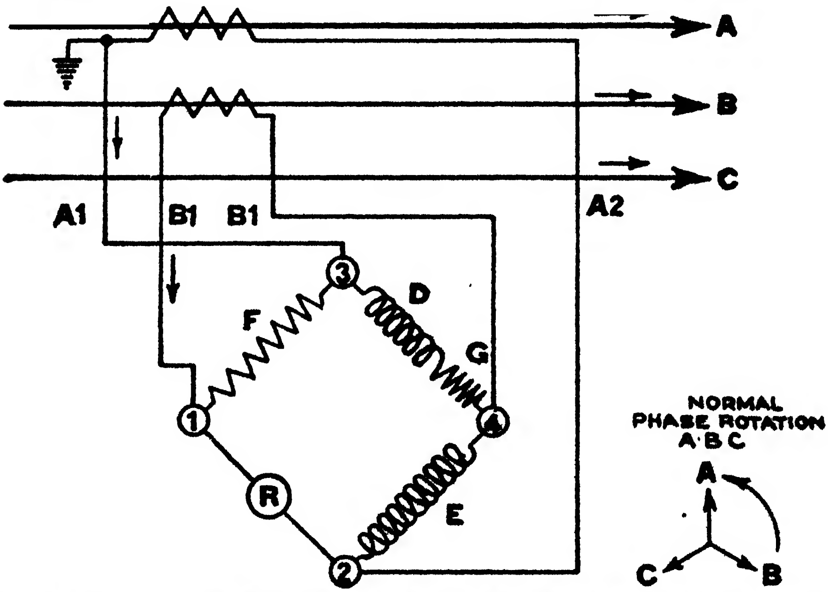
In the sub-station, the conditions are the reverse of those in the main station, the incoming lines becoming the source of power.

If there be only one incoming line and no high voltage bus, the line circuit breaker is generally non-automatic. With one incoming line and high voltage bus, the circuits from the service side of the bus are equipped with automatic circuit breakers and relays. These relays and those used for other arrangements of two or more incoming lines in parallel, as well as

high and low voltage circuit breakers, are of the same design and are applied in the same manner as for the generating station.

Regarding the relay equipment for auxiliary machines, the same practice is recommended with the generator end of alternating current motor generator sets as with the main generators, the outgoing feeder circuit breakers being tripped from inverse time limit or so called instantaneous relays.

With several synchronous machines in parallel, the relays are arranged to operate with the least time delay with which it is possible to get selective



FIGS. 4,234 and 4.235.—Diagram of external connections, Westinghouse phase balance current relay. *It consists* of four branches F, E, D, and R, which are connected in series and whose four corners are connected to two current transformers. These two current transformers are connected to two of the three phases of the circuit. F, resistance; D, plus G, an impedance; E, reactance; R, relay element itself, which is similar to the standard induction over current relay. The relay is so designed that no current flows through the relay element R, so long as the polyphase circuit is balanced and the phase rotation is correct. Upon the occurrence of one of the abnormal conditions mentioned above, the relay element receives an appreciable value of current and operates. The relay has two separate and distinct settings, one for amperes and the other for time element.

action, in order to prevent the machines being thrown out of step in event of trouble conditions causing a decrease of voltage.

The various types of *induction motor* and various conditions under which they are employed, have brought about the development of several types of relay to protect the motors and the apparatus with which they are used.

It is desirable to disconnect a *large motor* in case of voltage failure, and with conditions requiring either a motor operated, or a solenoid operated circuit breaker, a *low voltage relay* is used to close the tripping circuit whenever the voltage decreases to, approximately, 50 per cent. below normal.

Up to 550 volts, these relays may be connected across the line, but for higher voltages they are connected to secondaries of pressure transformers. *Smaller motors* with which hand operated circuit breakers are used, are generally provided with low voltage release attachments that perform the same function as the relay.

Induction motors are sometimes subjected to *high voltage conditions* and to protect them from injury, high or excess voltage relays are employed to trip the automatic circuit breaker. These relays are of similar design and wired in the same manner as the low voltage relays.

Reverse phase relays have been developed for operating conditions under which a *reversal of phase* would cause trouble, as for example, in the case of *elevator motors*.

These are so designed that any phase reversal that would reverse an induction motor would operate the relay and disconnect the automatic circuit breaker.

The design is based on the principle of the induction motor, and in the case of low voltage motors of limited capacity, the relay may be connected in series in the motor leads. If the voltage or capacity of the motor make this arrangement inexpedient, the relay may be placed in the secondaries of current or pressure transformers connected in the motor leads.

Underload relays are often used to trip the automatic circuit breaker that is placed in the primaries of *arc lighting circuits* to prevent an abnormal rise of secondary voltage in case of a break in the secondary circuit.

The underload relay is similar in design to the low voltage relay excepting that it acts on a decrease of current.

The problem of *protecting induction motors*, from injury that may result from running on single phase, or from an overload, and at the same time permit the motor to be started with the necessarily high starting current that may be greatly in excess of the overload current, has caused the development of the *series relay*.

This device may be connected in series with the motor leads for voltages up to 2,500; it is designed with an inverse time limit device which may be adjusted to give the desired protection.

The field for relays is more extensive for alternating current than for direct current power circuits, the latter being generally confined to much smaller and simpler systems and areas of distribution, and generally sufficient selective action can be obtained by the use of fuses or circuit breakers arranged with instantaneous trip.

Operating conditions sometimes make it advisable for the generator circuit breakers to open only after the auxiliary and feeder circuit breakers have failed to isolate the trouble.

This is accomplished by using direct current *series inverse time limit relays* to trip the generator circuit breakers.

**Instantaneous reverse current relays* are used to trip the machine circuit breaker of battery charging sets, rotaries and motor generator sets to prevent their running as a motor on the charging or direct current end. These relays can act only in case of current reversal.

*NOTE.—*Strictly speaking* the word *instantaneous* should never be used because it is impossible for any kind of a device to operate instantaneously. It is used for convenience to distinguish a very quick-acting device from others which require a longer time interval in their operation.

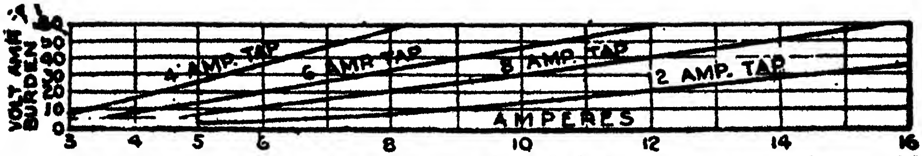


FIG. 2,436.—Characteristic curves showing burden placed on the current transformer with various currents flowing in the relay windings.

TEST QUESTIONS

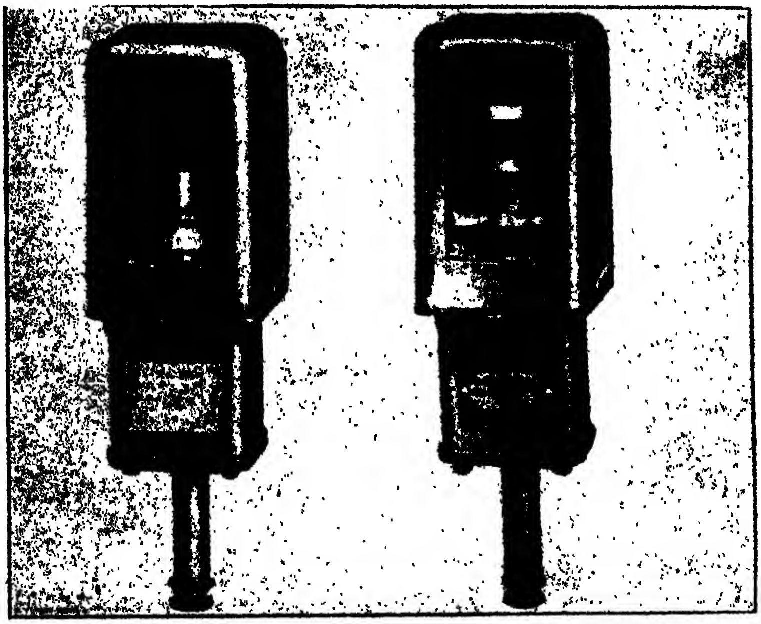
1. *What is a relay?*
2. *Name the various principles on which relays operate.*
3. *What is understood by the term inverse time?*
4. *What is the difference between inverse time and definite time?*
5. *Explain the terms directional and differential.*
6. *Explain over current with under voltage.*
7. *State the thermal principle.*
8. *Give classifications of relays.*
9. *How do protective relays operate?*
10. *How do regulating relays differ from protective relays?*
11. *What are communicative relays?*
12. *Explain the classification* a.c. *and* d.c. *relays.*
13. *What are circuit opening relays?*
14. *What is a circuit closing relay?*
15. *What is the difference between primary and secondary relays?*
16. *Describe an overload relay.*
17. *How does an under voltage differ from an over voltage relay?*
18. *Describe a reverse energy relay.*
19. *What is a reverse phase relay used for?*
20. *Explain the time element.*

21. *How do so called instantaneous relays operate?*
22. *Describe the construction and operation of a time limit relay.*
23. *Describe the construction of a differential relay.*
24. *How does an impedance or distance type relay work?*
25. *Describe the induction instrument type inverse time limit relay.*
26 *Give some general information on how to select a relay.*

CHAPTER 77A

Plunger Type Relays for Over-current and Auxiliary Service*

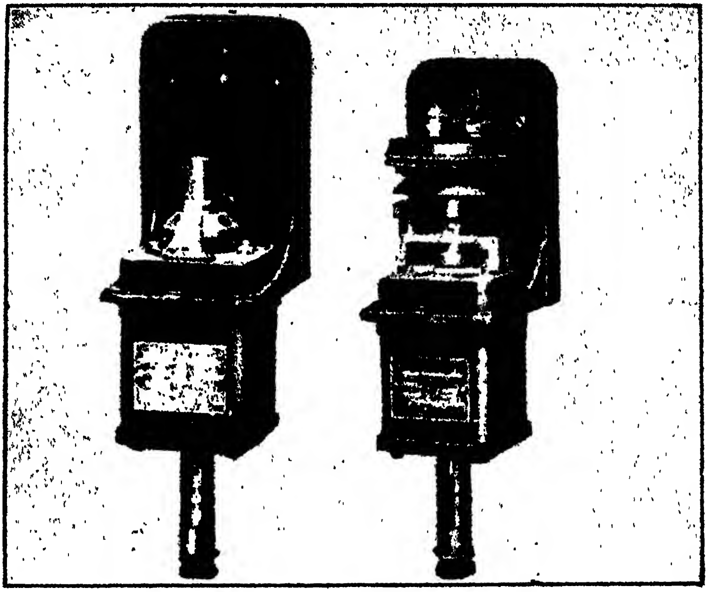
This group of relays operate on the solenoid principle and are shown in figs. 1 to 5.



FIGS. 1 and 2.—Plunger type over-current circuit, closing and circuit-opening relays respectively.

*The relays discussed are manufactured by the General Electric Co.

Each relay consists essentially of an iron clad operating coil and a movable plunger. The plunger actuates contacts which opens or closes the controlled circuit, depending upon the particular application.



FIGS. 3 and 4.—Relays with cover removed.

Operation Principles.—When due to certain conditions in the circuit to be protected, the current exceeds the value at which the relay is set to operate, the plunger raises and carries up with it the movable cone contact, or it strikes against the center of the toggle mechanisms, depending upon the type of contacts in the relay, the contacts are thus caused to function.

Generally, when a relay functions to open its contacts it is referred to as a *circuit-opening* type, and when it functions to close its contacts, it is referred to as the *circuit-closing* type. In this manner the function of the contacts of a relay is most frequently used as a means of identification, a relay being

circuit-closing or *circuit-opening* or *circuit-opening* and *circuit-closing*.

Timing Features.—In regard to speed of operation a relay may be referred to as instantaneous or *time* delay. The word *instantaneous* conveying a general qualifying term applied to any relay indicating that no delayed action has been purposely introduced.

The time relays are similar in construction to the instantaneous type, except for the addition of an air bellows which limits the rate of travel of the relay plunger, and in this way introduces an interval of time to the opening or closing of the relay contacts.

This time delay may be regulated to suit the special service desired, which is accomplished by means of a needle valve located in the head of the bellows as shown in fig. 5. This valve controls the rate of air flow from the bellows under various operating conditions.

All relays with timing features belong to either of two classes, namely: 1, Inverse time, and 2, Definite time.

The definite time relay is characterized by a compression spring interposed between an armature and a diaphragm of the air bellows. The contacts are actuated upon the movement of the diaphragm. With the function of the relay, the plunger tends to compress the spring which in turn reacts upon the diaphragm.

Again, for the inverse time relays, this spring is made stiff enough to resist the aforementioned compression except for a heavy overcurrent. Thus the time of operation is in inverse proportion to the over-current, and hence the definition *inverse time relay*.

Applications.—The aforementioned type of relays has a fairly broad field of application. However, it should be distinctly

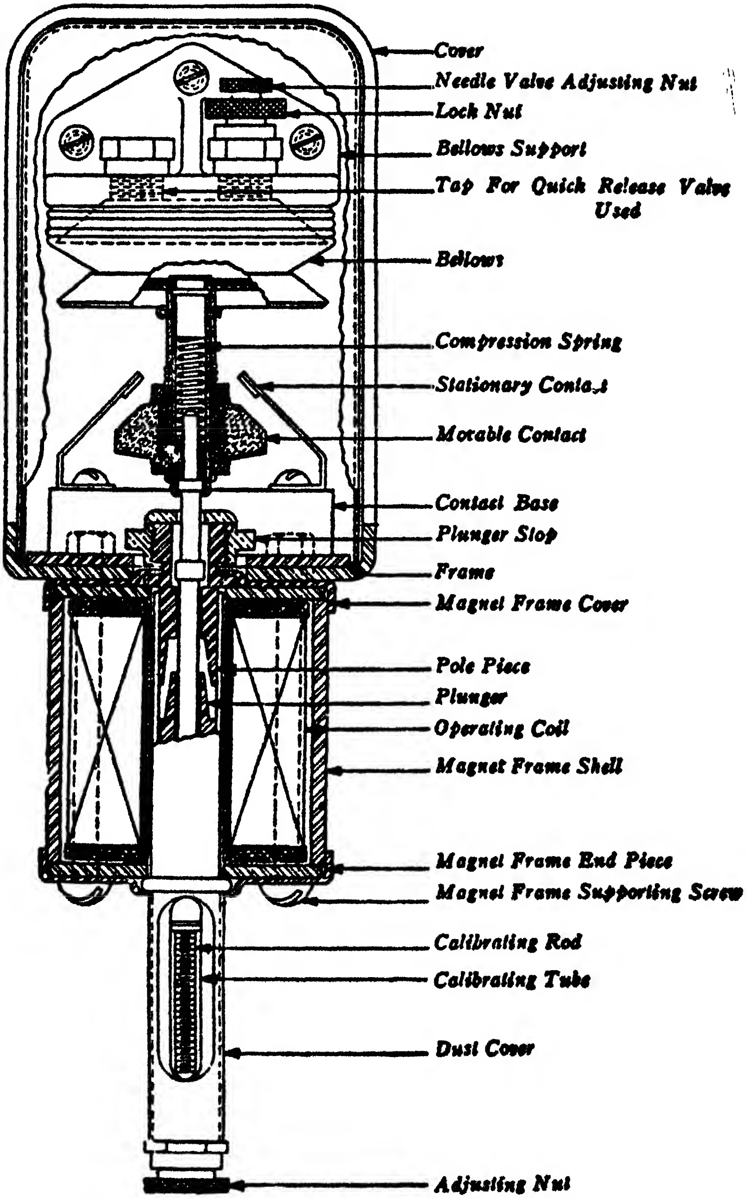


FIG. 5.—Cross-sectional view of standard unit plunger type over-current, circuit-closing relay, inverse time or definite time. When bellows is omitted this relay is practically instantaneous.

understood that the type described is not intended to cover all kinds and types of application permissible.

The various conditions attending individual installations very often vary, and hence each application should be carefully

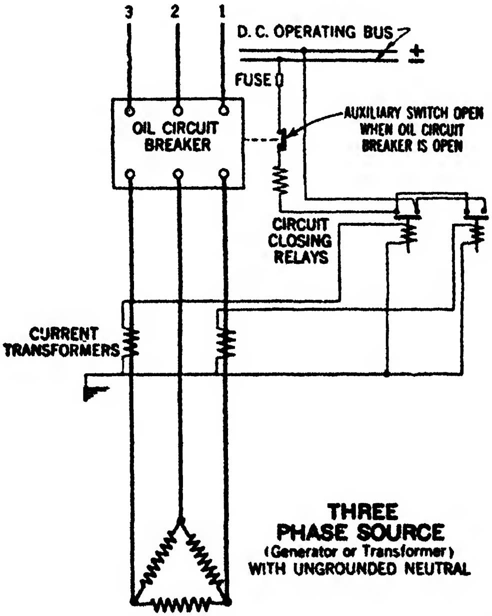


FIG. 6.—Indicating, method of connection for over-current circuit-closing relays when a direct current source be available for tripping of the oil circuit breaker. Normally the trip coil circuit is open at the relay contacts. When the over-current becomes sufficiently large for the relays to close its contacts, the trip coil becomes energized tripping the oil circuit breaker, removing the machine or source from the over-load.

analyzed and the type of relays selected which will most nearly perform to the desired operation features.

The application of the instantaneous and time relay is dependent upon local conditions and preferences. However, time relays are generally recommended where it is desirable to prevent interruption of the circuit where over-currents are only momentary.

The instantaneous types are most usually recommended where it is desirable to prevent damage, which may occur to machines and apparatus if not immediately disconnected from the source of load. For example, in the case of a large synchronous converter above 300 volt direct current, it is necessary to

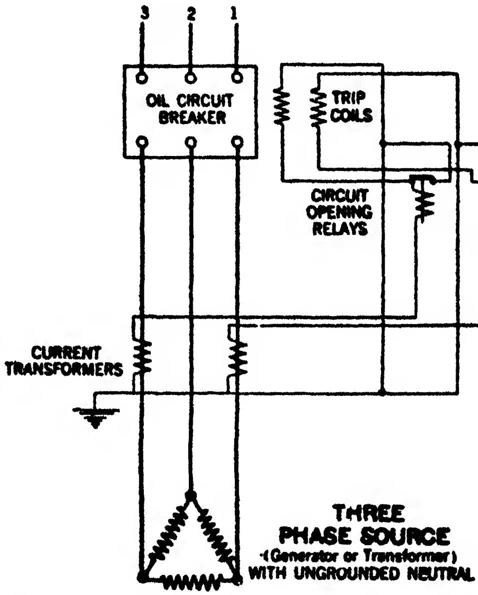


FIG. 7.—In this circuit over-current protection is accomplished by means of a set of current ...rs, with its associated relays and trip coils. In this system the relay contacts are normally closed. When the over-current through the coils exceeds that for which the relays are set to operate, the contacts opens, placing the trip coils in series with the relay coils, ... the trip coils to trip the circuit breaker.

disconnect the unit from the line as quickly as possible in order to assist in extinguishing commutator flash-overs when they occur. Time relays are used extensively for over-current protection of motors or other machine circuits where a simple time delay is desired.

In other applications, selective action may be desired and two or three stops of action are utilized. Systems of this kind are shown in figs. 8 and 9.

Locking Relays.—Sometimes due to special conditions, economy in oil circuit breakers may be effected by grouping a number of feeders together, controlled by one heavy duty breaker, and each separate feeder equipped with a light duty breaker.

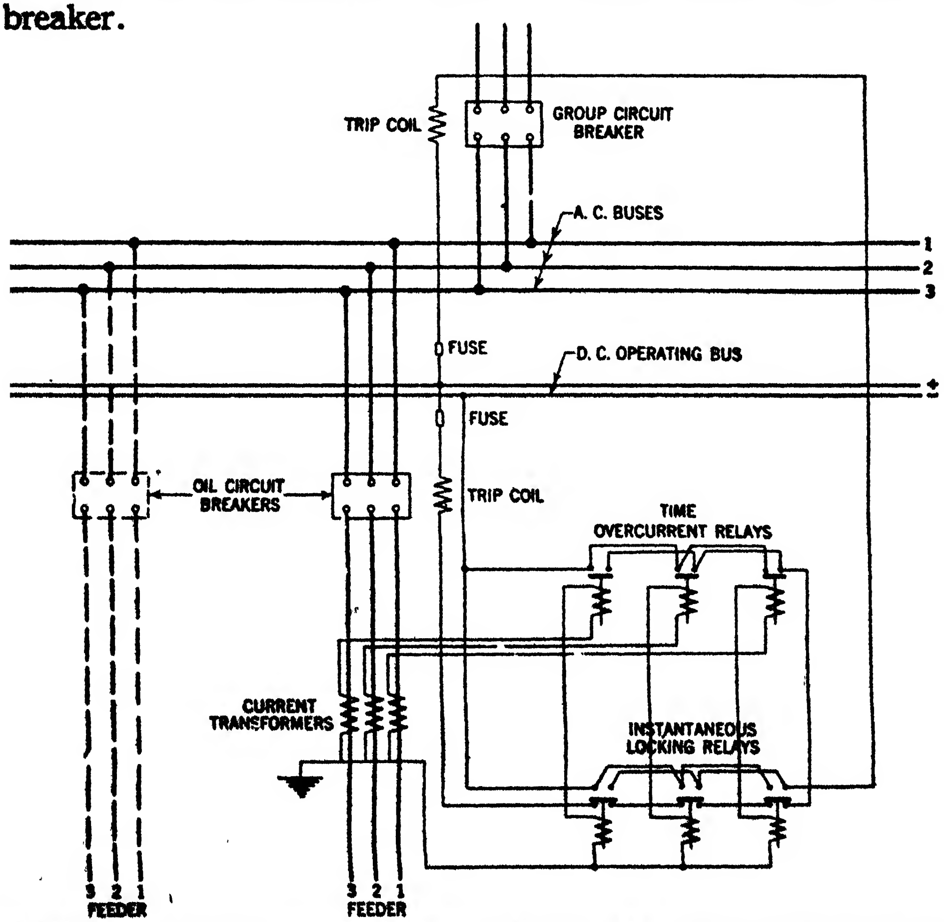


FIG. 8.—Group breaker connections with a set of locking relays, to protect feeder breakers on excessive current (Group breaker only tripped).

The feeder circuit breaker will have sufficient interrupting capacity to open the circuit upon the occasion of over-current, but not sufficient interrupting capacity to clear a short-circuit

or excessive over-current. In such cases locking relays, as shown in fig. 8, are employed to lock the feeder breaker in. In this system each feeder is equipped with a complement of time over-current relays adjusted to function to trip the feeder breaker on simple over-current, and a set of instantaneous locking relays with high current coils, adjusted not to function as long as the primary current does not exceed the capacity of the feeder breaker, but to function instantaneously in case the current exceeds this value.

The operation of the locking relays opens the tripping circuit of the feeder breaker, thus locking the feeder breaker closed, and closes the tripping circuit of the heavy duty group breaker.

It will be noted that all of the circuit opening contacts are in series and the circuit closing in parallel, which condition is necessary for satisfactory operation in case of trouble in any phase of the system.

Another method of application of locking relays to a group of feeder circuits is shown in fig. 9. Here as in the previously described circuit the locking relays operate only upon excessive over-current, in which case the locking relays closes the feeder breaker and opens the group breaker.

An additional relay equipped with a direct current coil is arranged to close instantaneously and reset (open) in a definite time is furnished as an auxiliary relay to work in conjunction with a circuit closing auxiliary switch on the group breaker to open the feeder breaker after the group breaker has opened.

In this manner the operator is able to close the group breaker, without having to find which feeder is in distress and to open its breaker as he would otherwise have to do.

Relay Calibration.—The setting of the relays, for operation at various currents passing through the coil, is accomplished by varying the position of the plunger in the coil. An adjustment

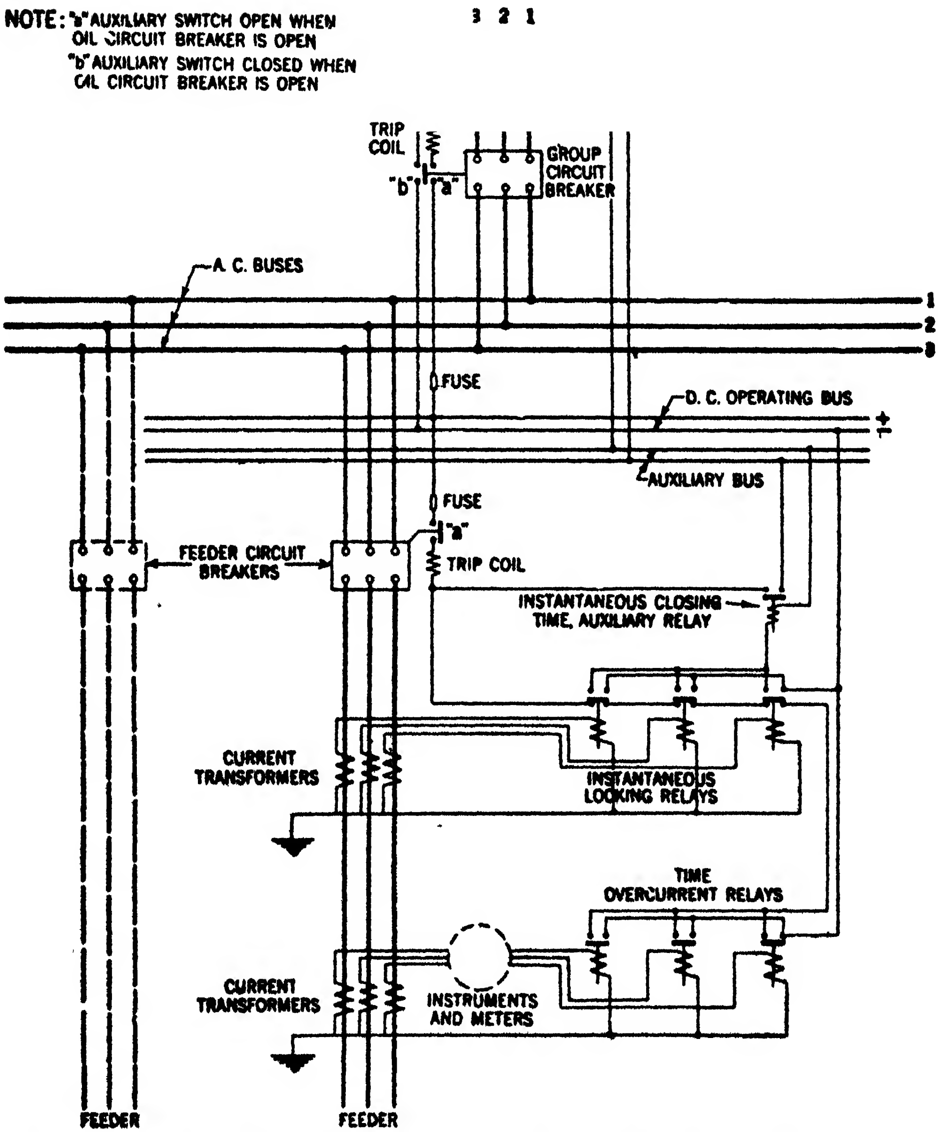


FIG. 9.—Group breaker connections with locking relays to protect feeder breakers on excessive current (Group breaker tripped and then faulty feeder breaker).

nut at the bottom of the calibration tube is provided for the purpose. The values marked on the calibrating tubes for both the instantaneous and time relays represent the minimum number of amperes in the relay coil, which will lift the plunger and open or close the relay contacts.

As already mentioned the time settings on all the inverse and definite time relays are obtained by means of a needle valve located on the top of the air bellows. This valve governs the escape of air from the bellows. With the valve wide open the operation of the relay is practically instantaneous. A knurled lock nut is provided for locking the needle valve after the adjustment is made. Time delays can be introduced by adjustment within the limits of approximately 2/10 to 20 seconds with 125% of the minimum current at which the relay is to function.

Relay Tests and Setting.—The method and care used in testing and setting of relays, often determines its proper functioning, and hence the proper operation of the power system.

It should be remembered that all tests should if possible be made under conditions as nearly equivalent to the operating conditions as possible, which makes it desirable to include all the wiring and complete relay equipment in the test.

The testing of the relay for time settings should be made with some form of timing device that gives absolutely accurate timing intervals. The stop-watch method is entirely inadequate for fine calibration.

The determination of relay settings must receive careful consideration. An analysis of all circuit conditions is necessary and a calculation of the short-circuit currents which may be produced at different points on the system is desirable so that the selective time-current characteristic curves can be made comparative for different points of the system under consideration.

The circuit contacts consist usually of carbon and may be adjusted for more or less contact pressure by bending the stationary contacts toward or away from the movable carbon cone.

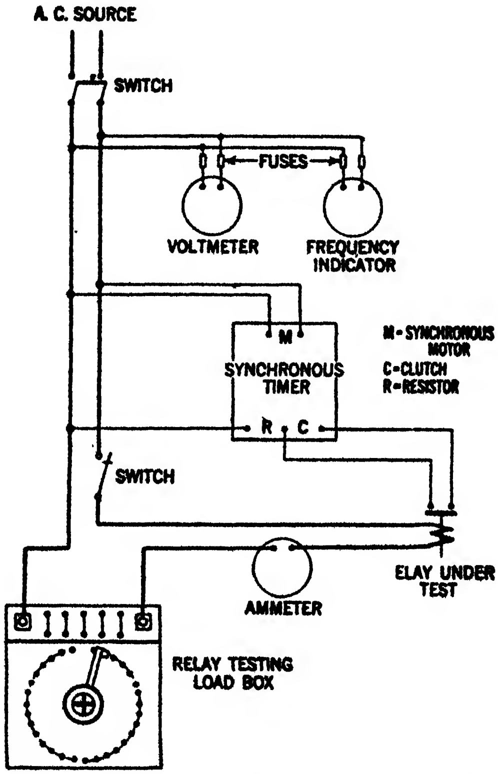


FIG. 10.—*Testing circuit* for *circuit-closing* relays. It should be noted that instrument employed in tests such as timers, frequency, volt and ammeters must be of precision type, otherwise the tests and setting of the relays cannot be accurately performed.

The amount of current through the contacts should not exceed 20 amperes for 1 minute or a continuous current of 2½ amperes.

Tripping Source.—It is of paramount importance that a reliable tripping source be available for the proper functioning

of the relays. The tripping source may be either *a.c.* or *d.c.* depending upon local conditions.

To mitigate the failure of the tripping source (as in the case of severe shorts in *a.c.* systems) tripping reactors are often used in connection with the relays.

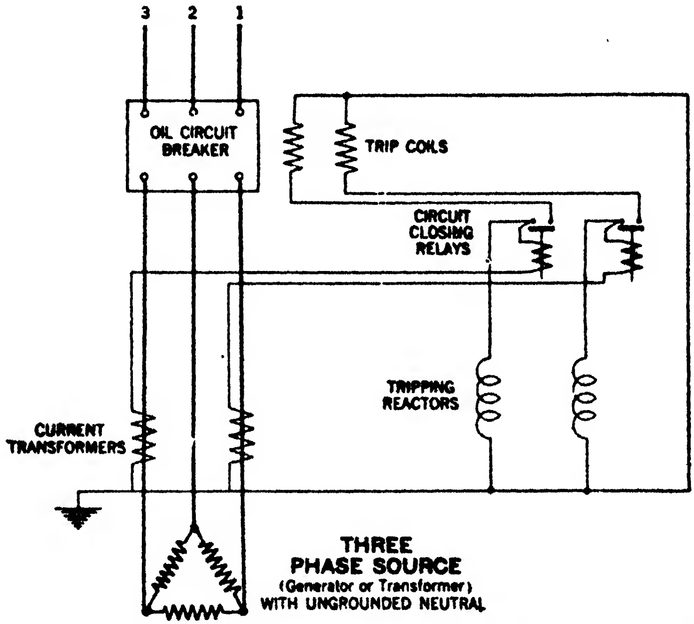


FIG. 11.—Over-current protection by means of circuit closing plunger type relays. When tripping reactors are used, as in over-current and other type of relays, instrument and meters should be connected from an extra set of current transformers. The tripping reactors are frequently employed when a direct current or reliable alternating current potential is not available as a tripping source for the relays. Normally the trip coil circuit is open and the reactor forms the closed circuit of the current transformer secondary. When the over-current is of a sufficiently high value to cause operation of the relay, it closes the trip coil circuit in shunt with the reactor causing sufficient current to be passed through the coil to trip the breaker.

In this case the trip coil circuit is open and the reactor forms the closed circuit of the current transformer secondary. When the relay operates it closes the trip coil circuit in parallel with the reactor, causing sufficient current to be diverted through the coil to trip the breaker. An application in which tripping reactors are employed is shown in fig. 11.

CHAPTER 78

Condensers

The economical operation of a generating and distributing system is dependent on the maintenance of a relatively high power factor. The reduction in the output of alternators, transformers and distributing feeders, as well as the increase in heating and losses, and the impaired voltage regulation resulting from low power factor loads, are of such nature in the power plant that the improvement of power factor is a matter of utmost importance.

Power Factor.—Although the author has given a whole chapter to power factor a brief explanation here is added for the convenience of the reader.

By definition power factor is *the ratio of power current to total current flowing in a circuit.*

When the voltage and current become out of phase, the current may be considered to be made up of two currents, one in phase with the voltage and the other 90° out of phase with it. The out of phase current is called the reactive or wattless component. It is stored energy that is being transferred back and forth through the circuit with no resulting losses, except the heat losses due to resistance. This loss occurs in the line and in all current carrying parts.

When the power factor becomes low, *large amounts of energy are expended in heating up conductors that would, under proper operating conditions, be available for useful work.*

An inductance in a circuit will cause the current to lag with respect to the voltage and a capacity will cause it to lead the voltage. Under either condition there is a reactive component of the current with a consequent lowering of the power factor. The ideal condition would be where the inductance and capacity balance so that the current and voltage would be in phase. In this case the power factor would be 100%. In the majority of cases low power factor is due to the current lagging the voltage.

Apparatus such as transformers and induction motors having magnetic fields require a magnetizing *kva.* just as a generator requires field excitation. This magnetizing *kva.* is 90° out of phase with the voltage and adds

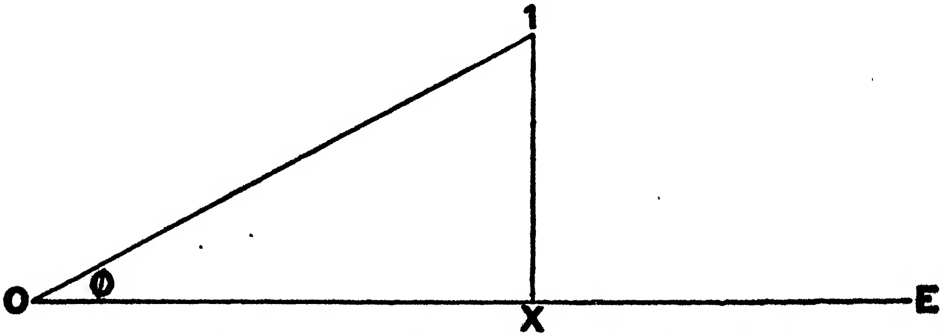


FIG. 4,237.—Simple vector diagram by which most power factor problems may be solved. OI, is the actual current which lags behind the voltage OE, by the angle ϕ. The active component in phase with the voltage is OX, and the reactive component 90° out of phase is IX. The power factor of a circuit is the ratio of the active component of the current to the actual current $\frac{OX}{OI}$ which is the cosine of angle ϕ. The common definition of power factor is *the ratio of the power to the apparent power*. The apparent power in a three phase circuit is $\sqrt{3}$ EI, which is *kva.* and the actual power is, $\sqrt{3}$ EI cosine ϕ, which is *kva.* times power factor and equals *kw.* It is apparent that *kva.* and *kw.* are one and the same thing at unity power factor and that for power factors other than unity, the current for a given *kw.* load changes inversely with the power factor. These curves terminate at the safe current carrying capacity of this particular line; the various curves show clearly the increased line loss at the lower power factors, as well as the decrease in safe load carrying capacity with decrease in power factor.

to the wattless component that is carried by the line. Lightly loaded transformers or induction motors reduce the power factor to a much greater extent, than when fully loaded, because the wattless component is greater in proportion.

Induction motors and other inductive apparatus take a component of

current which lags behind the line voltage and thereby lowers the power factor of the system, while a non-inductive load, such as incandescent lamps, takes only current in phase with the voltage and operates at 1.0 power factor. As transformers require magnetizing current, they may seriously affect the power factor when unloaded or partially loaded, but when operating at full load their effect is practically negligible. The relative effect of fully loaded and lightly loaded induction motors on power factor in indicated in fig. 4,241. The magnetizing current is nearly constant at all loads and is wattless, lagging 90° behind the impressed voltage, or at right angles to the current which is utilized for power.

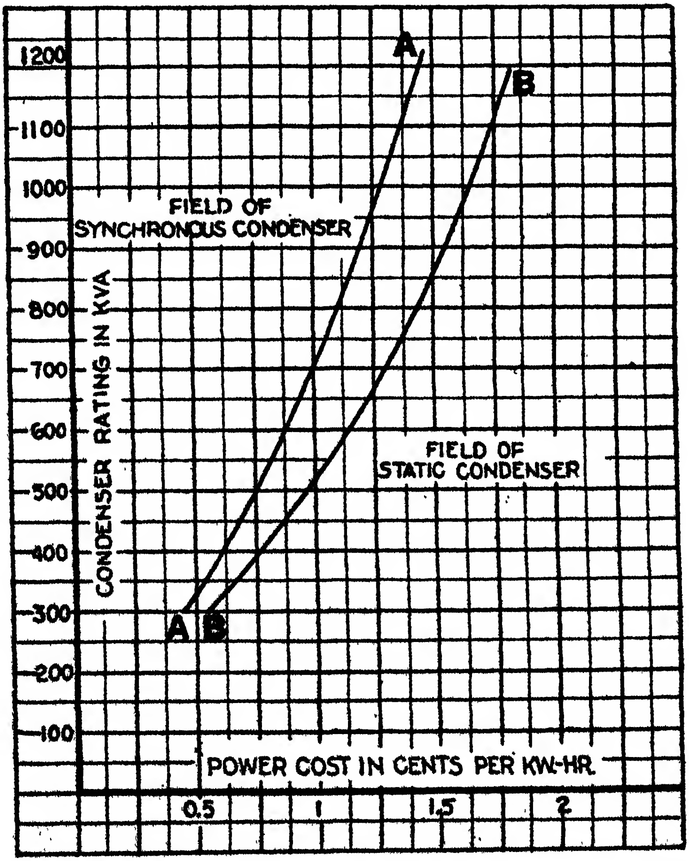


FIG. 4,238.—Curves showing fields of application for static and synchronous condensers 2,300 volt service, 60 cycles.

Effect of Low Lagging Power Factor.—Low power factor operation results in *increased losses in alternators, exciters, distribution lines, transformers, and in the consumer's plant.* In a system working at 70% power factor the losses will be twice as great as they will if working at unity power factor. This increased loss is caused by increased currents for the same amount of power, and stronger fields are needed by the alter-

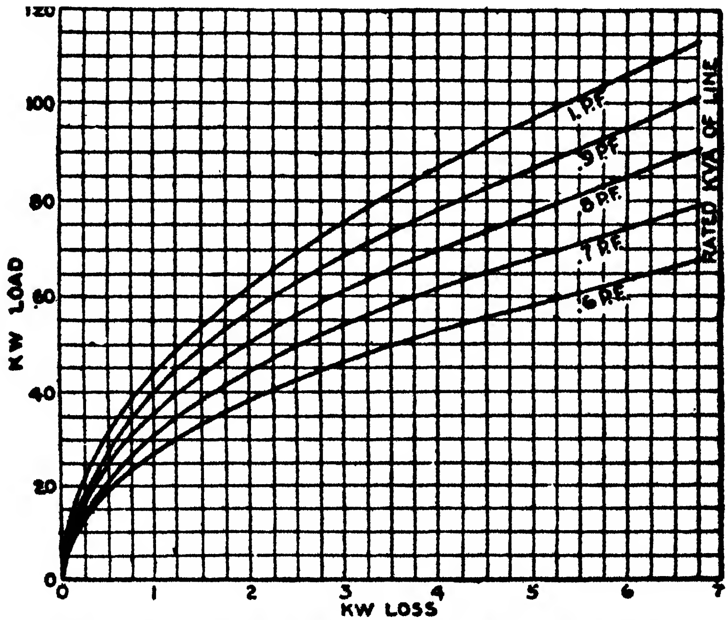


Fig. 4,239.—Curves showing line loss for a 1000 ft. No. 0 wire, 3 phase, 60 cycle circuit, 9 in spacing, 440 volts at motor These curves terminate at the safe current carrying capacity of this particular line; the various curves show clearly the increased line loss at the lower power factors, as well as the decrease in safe load carrying capacity with decrease in power factor.

nators to furnish this power which causes undue heating. It follows from this, that if the losses be kept the same at 70% power factor as they are at unity power factor, the cross section of the copper will have to be doubled.

The following formula gives the currents at various power

factors that will be required to carry a 75 *kw.*, 550 volt, single phase motor load:

$$I = \frac{\text{Watts}}{E\ (\%)\ P.F.}$$

These currents for power factor 100 to 50 are given in the following table:

Currents for Various Power Factors

% Power Factor	100	90	80	70	60	50
Current	136.3	151.5	170.5	195	228	273
Kva	75	83	94	107	125	150

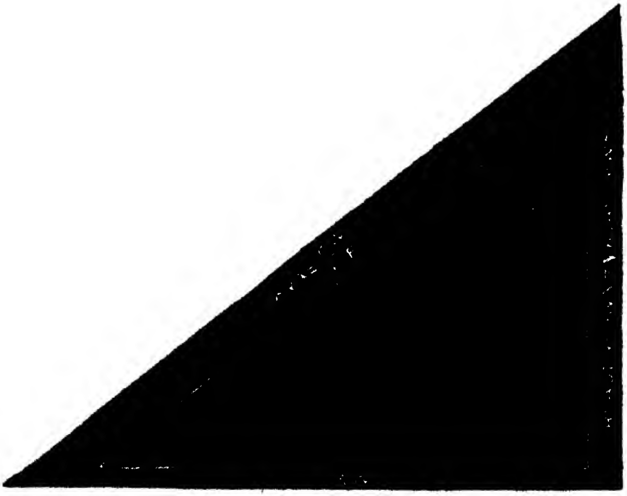


Fig. 4,240.—Vector diagram of a typical *a.c.* load.

Another factor that this table shows well, is that at lower power factors, there is considerable line drop, which necessitates impressing over voltage at the supply end, making the voltage regulation poor.

The regulation of transformers is approximately 1% at unity power factor, and 3% at 70% power factor.

The relative effect of fully loaded and lightly loaded induction motors on the power factor is indicated by the diagram,

fig. 4,241. The magnetizing current is nearly constant at all loads and is wattless, lagging 90 degrees behind the impressed pressure, or at right angles to the current which is utilized for power.

In the figure, AB is the magnetizing component, which is always wattless, and CB the power component. The angle ACB, gives the phase relation between voltage and current; the cosine of this angle CB÷AC is the power factor.

It is evident from the diagram that if the load be reduced, the side

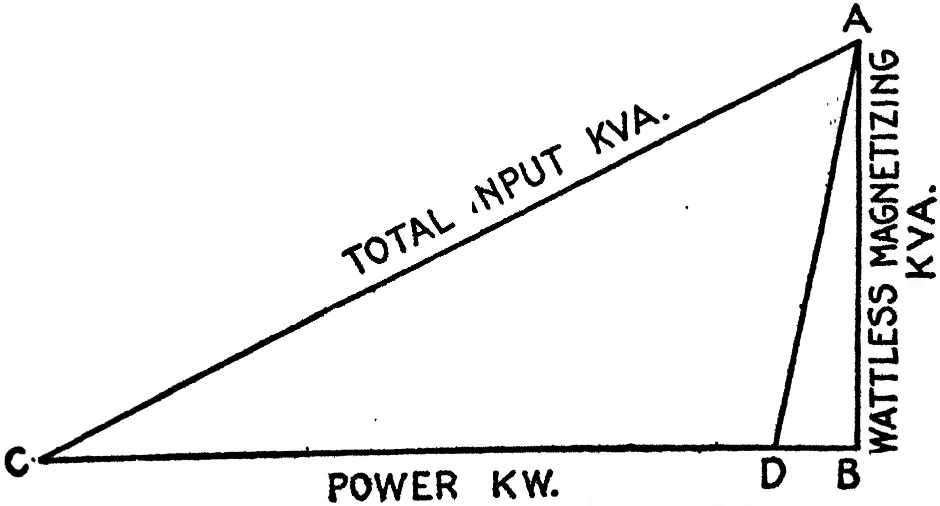
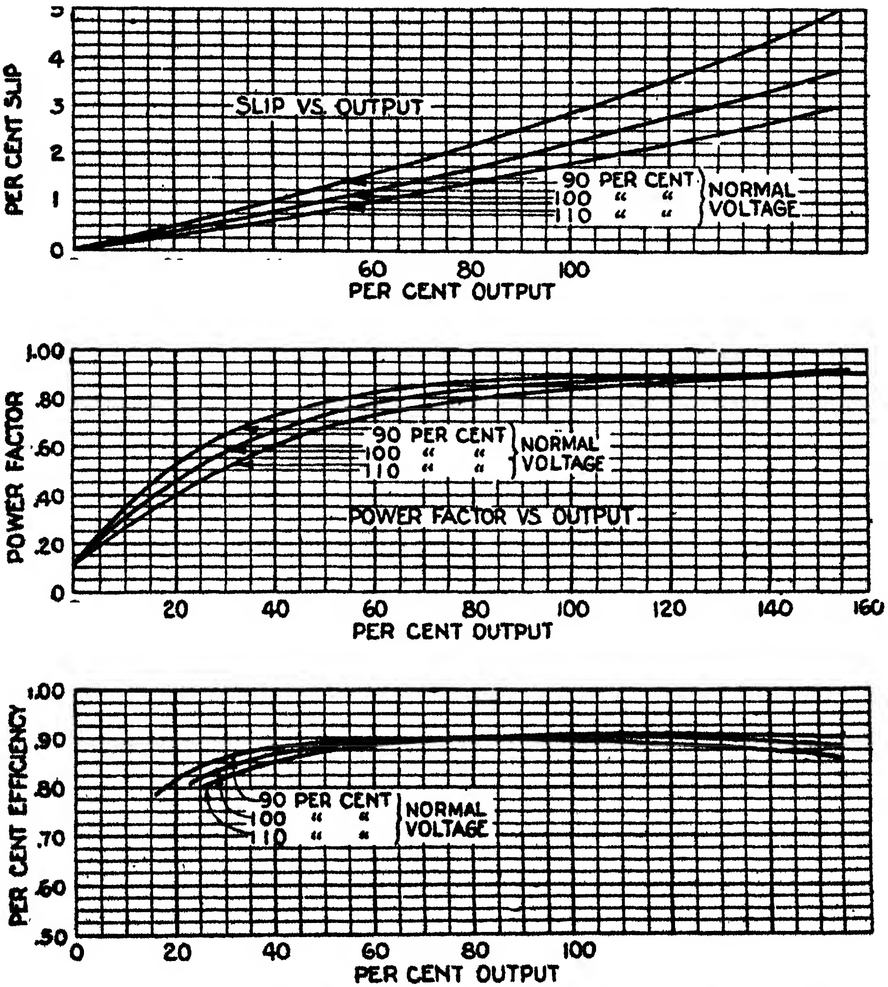


FIG. 4,241.—Diagram showing relative effect of fully loaded and lightly loaded induction motors on power factor.

CB, is shortened, and as AB, is practically constant, the angle of lag ACB, is increased. It therefore follows that the cosine of this angle, or the power factor is reduced.

The figure clearly shows the reason for the low power factor of induction motors on fractional loads and also shows that since the magnetizing current is practically constant in value, the induction motor can never operate at unity power factor.

With no load, the side CB (real power), is just sufficient to supply the friction and windage. If this be represented by DB, since AB, remains constant, the power factor is reduced to 10 or 15 per cent. and the motor takes from the line about 30 per cent. of full load current. It therefore



FIGS. 4,242 to 4,244.—Characteristic curves for a 3 phase, squirrel cage induction motor. These curves show the effects of under voltage and over voltage upon induction motors. It will be noted in this respect that a variation of voltage of 10% either side of normal has very little effect on induction motors other than on the slip. Voltages below normal reduce the speed of the motor, and consequently, affect production adversely. The torque of induction motors varies with the square of the voltage applied, consequently, if the voltage drop more than 10% below normal, it is not only the abnormal reduction in speed due to increased slip that becomes serious, but also the liability of stalling the motors and the other apparent disadvantages, such as lower efficiency and overheating of the motor. Poor lighting conditions also accompany low voltage. Consequently, low power factor circuits require expensive voltage regulating equipment or the quality of service is inferior and results in operating and production difficulties.

follows that a group of lightly loaded induction motors can take from the system a large current at exceedingly low power factor.

Transformers are rated in *kilovolt ampere output* that is, a 100 *kva*. transformer is supposed to deliver 100 *kw*. at unity power factor at normal voltage and at normal temperature; but if the power factor be .6 lagging, the rated energy output of the transformer would be only 60 *kw*. and yet the current and consequently the heating, would be approximately the same as when delivering 100 *kw*. at unity power factor.

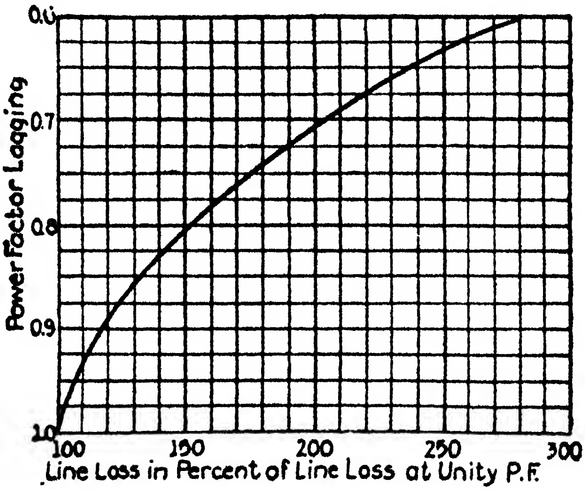


FIG. 4,245.—Curve showing relation between power factor and line loss when carrying constant *kw*. load.

The regulation of transformers is inherently good, being for small lighting transformers about 1½ to 2 per cent. for a load of unity power factor, and about 4 or 5 per cent. at .7 power factor. Larger transformers with a regulation of 1 per cent. or better at a unity power factor load would have about 3 per cent. regulation at .70 power factor.

Alternators are also rated in *kva*. output, usually at any value of power factor between unity and .8.

The deleterious effects of low power factor loads on alternators are even more marked than on transformers. They are: decreased kilowatt capacity, decreased efficiency, impaired voltage regulation, and the necessity for increased exciter capacity.

Example.—In the case of a 200 *kva*. alternator designed for .80 power factor (160 *kw*. output), if the power factor in the circuit supplied by this alternator, be about .6, it is probable that normal voltage could be obtained only with difficulty even though at this power factor the alternator would be delivering no more than 120 *kw*. The lagging power factor current in the armature sets up a flux which opposes the flux set up by the fields, and in consequence tends to demagnetize them, resulting in low

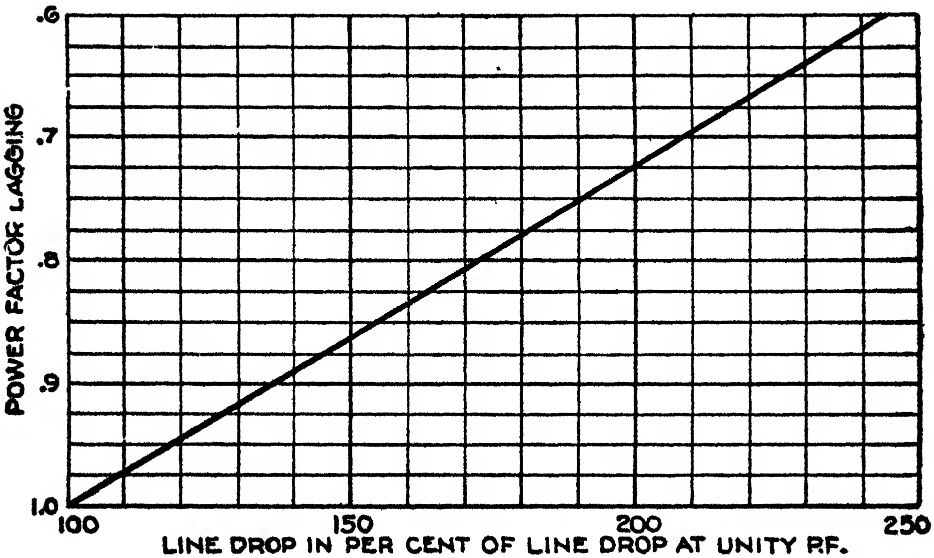


Fig. 4,246.—Curve showing relation between power factor and line drop for constant *kw.* load over a 1000 ft. 3 phase, 60 cycle circuit of No. 0 wire, 9 in. spacing, 440 volts at motor. It will be noted that the drop increases more rapidly than the power factor decreases, which in turn is due to the reactance of the circuit. This circuit might be considered as typical.

armature voltage. It is often impracticable, without the installation of new exciters, to raise the alternator voltage by a further increase of the exciting voltage and current.

The field losses, and therefore, the field heating of the alternator, when it is delivering rated voltage and current, are greater at lagging power factor than at unity. Increased energy input and decreased energy output both cause a reduction in efficiency.

The regulation at unity power factor of modern alternators capable of

carrying 25% overload is usually about 14%. Their regulation at .7 power factor lagging is about 30%.

The effect of low power factor on the lines can best be shown by examples.

Example.—Assume a distance of two miles and a load of 100 *kw*. It is desired to deliver this load at about 2,300 volts, 3 phase, 60 cycles, with an energy loss of 10%.

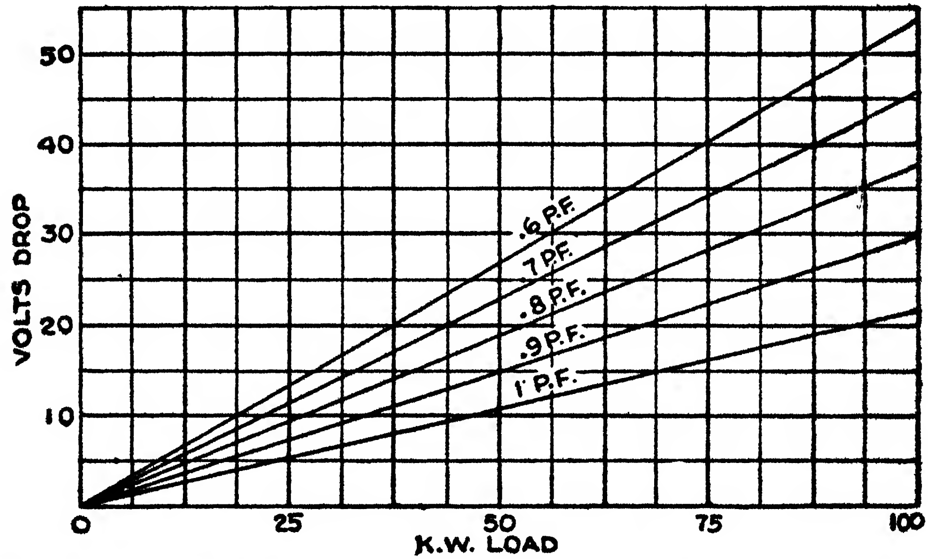


FIG. 4,247.—Curves showing volts drop over a 1,000 ft. 3 phase, 60 cycle, circuit of No. 0 wire, 9 in. spacing, 440 volts at motor. The curves show the actual volts drop in this circuit carrying various loads at various power factors. These curves are intended to give a picture of the effect of reduction of power factor and are not intended to be used in actual calculations.

Each conductor at unity power factor would require an area of 25,000 cir. mils; at .9 power factor, 30,820 cir. mils, while at .6 power factor, 69,500 cir. mils would be necessary. From this is will be seen that the investment in copper will have to be nearly 2.8 times as much at .6 power factor as at unity. If the same size wire were used at .6 as at unity, the energy loss would be 2.8 times the loss at unity, or 28%. Low lagging power factor on a system, therefore, will generally mean limited output of the prime movers, greatly reduced kilowatt capacity of alternators, transformers and lines, as well as increased energy losses. The regulation of the entire system will also be poor.

Example.—Assuming a distance of five miles and a load of 1,000 *kw.* and desiring to deliver this load at a pressure of about 6,000 volts, three phase, with an energy loss of 10 per cent., each conductor at unity power factor would have to be 79,200 cm., at .9 power factor, 97,533 cm., and at .6 power factor, 218,000 cm. In other words, at the lower power factor of .6, the investment in copper alone would be 2.8 times as much.

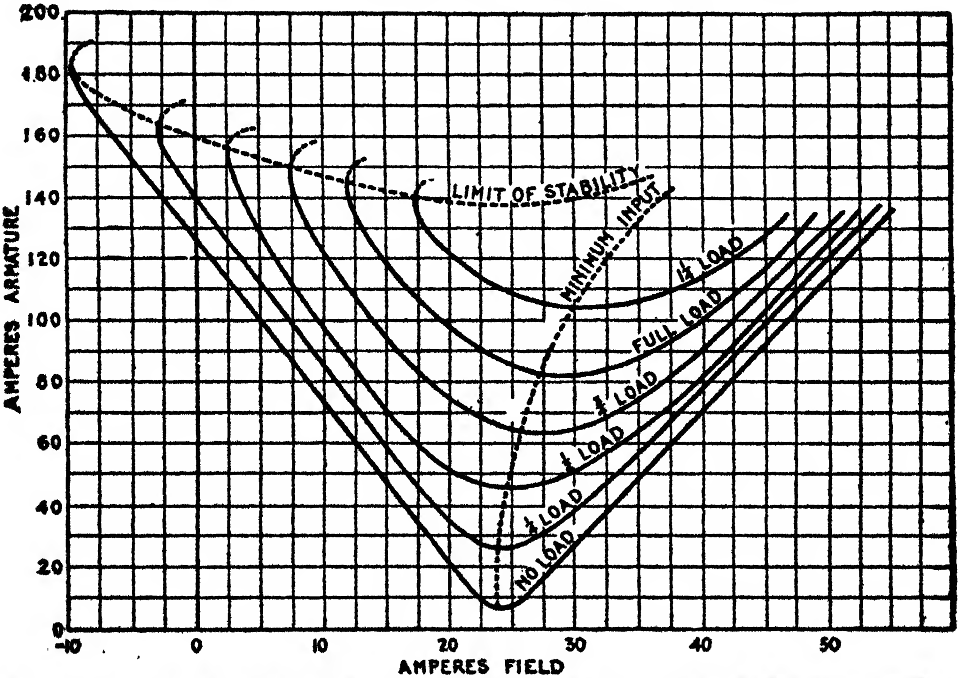


FIG. 4,248.—Diagram showing a set of *phase characteristic curves* taken from a General Electric *synchronous motor*. *These curves show the current input to the motor at various loads with constant voltage and varying field excitation.* There is a certain field current at each load that causes a minimum current. Any increase or decrease of field from the value increases the current and causes it to lead or lag with respect to the line voltage.

If the same size of wire were used at both unity and .6 power factor lagging, the energy loss would be about 2.8 times the loss at unity power factor, or about 28 per cent. Low lagging power factor on a system, therefore, will generally mean limited output of prime movers; greatly reduced kilowatt capacity of generator, transformer and line; and increased energy losses. The regulation of the entire system will also be poor.

Cost of Synchronous Condenser vs. Cost of Copper.—Referring to the example given in the preceding paragraph, and

calculating the necessary extra investment in copper with the .6 power factor load, and copper at 17 cents per pound, the result is that 29,292 pounds more copper is required than with the power factor of .9 which means a total extra investment in copper alone of \$5,000 (29,292 × \$.17).

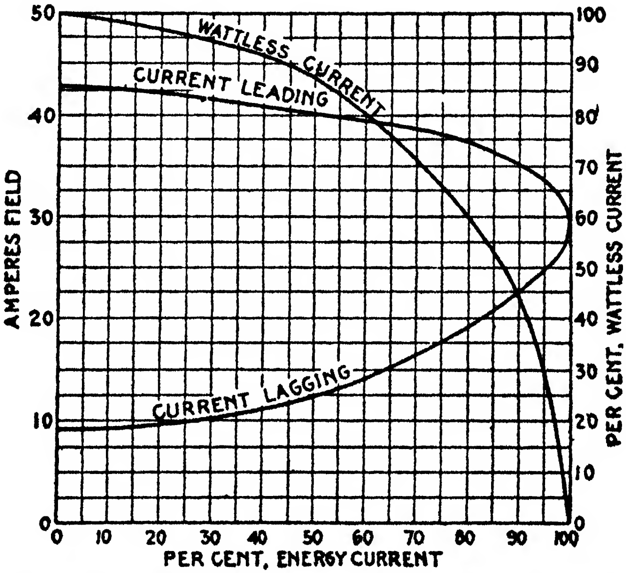


Fig. 4,249.—Diagram showing the ***field current taken by a synchronous motor*** of normal design when operating at normal *kva.* input at various power factors. ***It will be noted*** that a ***slight departure from unity power factor necessitates a considerable change in field current.***

A synchronous condenser of sufficient capacity to accomplish the same result would cost about the same amount. It would therefore cost less to install the condenser because at the same time a considerably increased capacity would be obtained from the alternators, transformers, etc.

Cause of Low Lagging Power Factor.—In general, on systems where the power factor is low the cause is *almost entirely induction motors.*

Unreasonably low power factor will usually be found due to: 1, The use of motors of inferior design and construction

requiring larger magnetizing current than necessary; 2, the use of motors too large for the duty they perform; 3, the practice of allowing motors to run idle or lightly loaded.

The exciting current is practically constant, irrespective of load. If the motor be carrying less than full load, the in-phase component is less, and since the reactive component remains the same, the angle of lag θ becomes greater and the cosine θ or power factor becomes less.

With the motor running light the in-phase component is just sufficient to supply the friction and windage and core losses of the motor, the power factor is reduced to 10 or 15% and the motor takes about 35% of full load current.

The effect of the magnetizing current of transformers is practically negligible when operating at or near full load, but a large number of unloaded or partially loaded transformers on the line may seriously affect the power factor.

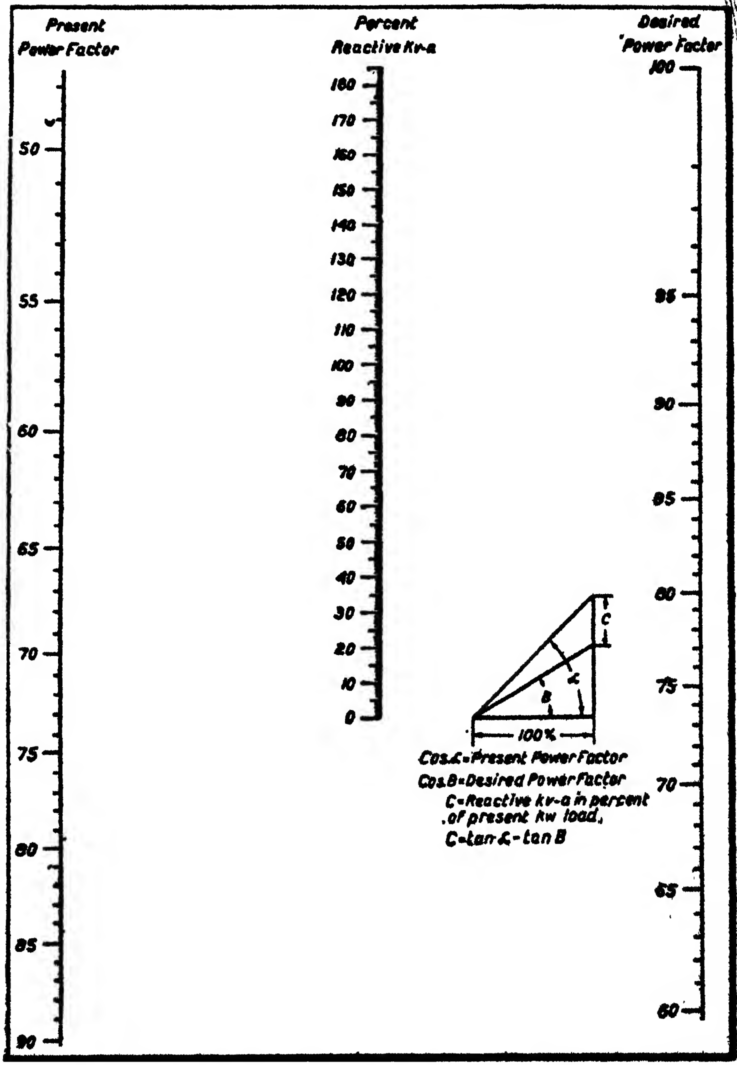
Advantage of Improving the Power Factor.—It is apparent from the disadvantages of low power factor, that there are corresponding advantages of high power factor, and, therefore, it is to the advantage of the ultimate consumer to obtain the highest possible power factor consistent with economy.

It is a problem of balancing the benefits obtained such as lower charges from the power company, lower investments within the plant and improved operating conditions, against the increased cost of equipment necessary to improve the power factor.

The benefits obtained naturally depend largely upon the particular case

Improving the power factor in an industrial plant might mean the avoidance of installing an additional alternator, additional transformers or additional lines. It might mean a considerable saving in power bills due to better rates and, in addition, a saving in losses, in transformers, lines and motors sufficient to warrant investment in power factor improvement devices. It might mean an improvement of voltage conditions, such as to increase production as a result of maintaining rated speeds of induction motors. Improved lighting and voltage conditions might

Power Factor Chart



FIGS. 4,250 to 4,253.—Chart for use in determining the per cent reactive *kva*. required to raise the power factor to a desired value. *Example:* To find the "per cent reactive *kva*." necessary to raise the power factor from present power factor to desired power factor, lay a straight edge across the chart connecting these two values. Read the reactive *kva*. in per cent of the present *kw*. load on the middle scale.

Power Factor Improvement—Table 1

(The figures below × kilowatt input = leading *kva*. required to improve from one power factor to another.)

Original Power Factor %	Desired Power Factor 100 %	95 %	90 %	85 %	80 %
20	4.899	4.570	4.415	4.279	4.149
21	4.656	4.327	4.171	4.036	3.906
22	4.433	4.104	3.949	3.813	3.683
23	4.231	3.902	3.747	3.611	3.481
24	4.045	3.716	3.561	3.425	3.295
25	3.873	3.544	3.389	3.253	3.123
26	3.714	3.385	3.229	3.094	2.964
27	3.566	3.238	3.082	2.946	2.816
28	3.429	3.100	2.944	2.809	2.679
29	3.300	2.971	2.816	2.680	2.550
30	3.180	2.851	2.696	2.560	2.430
31	3.067	2.738	2.583	2.447	2.317
32	2.961	2.632	2.476	2.341	2.211
33	2.861	2.532	2.376	2.241	2.111
34	2.766	2.437	2.282	2.146	2.016
35	2.676	2.347	2.192	2.056	1.926
36	2.592	2.263	2.107	1.972	1.842
37	2.511	2.182	2.027	1.891	1.761
38	2.434	2.105	1.950	1.814	1.684
39	2.361	2.032	1.877	1.741	1.611
40	2.291	1.963	1.807	1.671	1.541
41	2.225	1.896	1.740	1.605	1.475
42	2.161	1.832	1.676	1.541	1.410
43	2.100	1.771	1.615	1.480	1.349
44	2.041	1.712	1.557	1.421	1.291
45	1.985	1.656	1.501	1.365	1.235
46	1.930	1.602	1.446	1.310	1.180
47	1.877	1.548	1.392	1.257	1.128
48	1.828	1.499	1.343	1.208	1.077
49	1.779	1.450	1.295	1.159	1.029
50	1.732	1.403	1.248	1.112	.982
51	1.687	1.358	1.202	1.067	.936
52	1.643	1.314	1.158	1.022	.892
53	1.600	1.271	1.116	.980	.850
54	1.559	1.230	1.074	.939	.808
55	1.518	1.189	1.034	.898	.768
56	1.479	1.150	.995	.859	.729
57	1.442	1.113	.957	.822	.691
58	1.405	1.076	.920	.785	.654
59	1.368	1.040	.884	.748	.618
60	1.333	1.004	.849	.713	.583
61	1.299	.970	.815	.679	.549
62	1.266	.937	.781	.646	.515
63	1.233	.904	.748	.613	.483
64	1.201	.872	.716	.581	.450
65	1.169	.840	.685	.549	.419
66	1.138	.810	.654	.518	.388
67	1.108	.779	.624	.488	.358
68	1.078	.750	.594	.458	.328
69	1.049	.720	.565	.429	.299
70	1.020	.691	.536	.400	.270
71	.992	.663	.507	.372	.241
72	.964	.635	.480	.344	.214
73	.936	.608	.452	.316	.186
74	.909	.580	.425	.289	.159
75	.882	.553	.398	.262	.132
76	.855	.527	.371	.235	.105
77	.829	.500	.344	.209	.078
78	.802	.474	.318	.182	.052
79	.776	.447	.292	.156	.026
80	.750	.421	.266	.130	
81	.724	.395	.240	.104	
82	.698	.369	.214	.078	
83	.672	.343	.188	.052	
84	.646	.317	.162	.026	
85	.620	.291	.136		
86	.593	.265	.109		
87	.567	.238	.082		
88	.540	.211	.056		
89	.512	.183	.028		
90	.484	.155			
91	.456	.127			
92	.426	.097			
93	.395	.066			
94	.363	.034			
95	.329				
96	.292				
97	.251				
98	.203				
99	.142				
100					

Example.—Total *kw.* input of plant from watt meter reading 100 *kw.* at a power factor of 60%. The leading reactive *kva* necessary to raise the power factor to 90% is found by multiplying the 100 *kw* by the factor found in the table which is .849. 100 *kw.* × .849 = 84.9 *kva.* If static condensers be used, choose the standard unit nearest to 84.9. If synchronous motors be used, see example under the table on page 2,410.

further mean a considerable saving in maintenance, as low voltage usually results in overheating of motors, transformers and cables.

How to Improve the Power Factor.—In a plant the power factor may be improved to some extent *by re-arrangement of the motors so that they will operate more nearly at full load.*

Even after the motors are correctly applied, production requirements may vary, demanding motor sizes that result in poor load factors, and consequently, poor power factor conditions, because they are not fully loaded at all times. It is usually impossible to secure good power factor conditions,

Power Factor Improvement—Table 2

P.F.	Reactive Kv-a.	P.F.	Reactive Kv-a.	P.F.	Reactive Kv-a.
1.00	.000	.83	.672	.66	1.138
.99	.142	.82	.698	.65	1.169
.98	.203	.81	.724	.64	1.201
.97	.251	.80	.750	.63	1.233
.96	.292	.79	.776	.62	1.266
.95	.329	.78	.802	.60	1.299
.94	.363	.77	.829	.60	1.333
.93	.395	.76	.855	.59	1.368
.92	.426	.75	.887	.58	1.405
.91	.456	.74	.909	.57	1.442
.90	.484	.73	.936	.56	1.479
.89	.512	.72	.964	.55	1.508
.88	.540	.71	.992	.54	1.559
.87	.567	.70	1.020	.53	1.600
.86	.593	.69	1.049	.52	1.643
.85	.620	.68	1.078	.51	1.687
.84	.646	.67	1.108	.50	1.732

NOTE.—The figures in the table show the amount of reactive *kva.* for each *kw.* energy load at various power factors. For synchronous motors, the figures show the leading reactive *kva.* per *kw.* input. For induction motors or a load with lagging power factor, the figures show the lagging reactive *kva.* per *kw.* energy load.

Example.—Refer to table on page 2,409 Assume improvement desired by substitution .8 power factor synchronous motor for induction motors. For each *kw.* load driven by induction motors operating at average power factor of .6, the table shows there is 1.333 lagging reactive *kva.*For each *kw.* input in .8 power factor synchronous motor, the table shows a leading reactive *kva.* of .75. If .8 power factor synchronous motors replace .6 power factor induction motors, each *kw.* in synchronous motors reduces the lagging reactive *kva.* 1.333+.75 =2.083 *kva.* The total reduction necessary to improve the power factor is shown by table on page 2,409 to be 84.9 *kva.* The capacity in .8 power factor synchronous motor required is 84.9 ÷2.033 = 40.8 *kw.* A 50 *h.p.*—.8 power factor motor should be recommended.

without the use of some *corrective device*, but, before installing devices to supply it, the magnetizing *kva*. should be reduced to the minimum.

There are two kinds of corrective device used to correct the power factor:

1. Synchronous condenser;
2. Static condenser.

The choice between these two types depends on the conditions in the industrial plant. The substitution of a few comparatively large synchronous motors in place of induction motors, where conditions are suitable, often is the most economical method of improving the power factor.

The usual application is met best, by the simple squirrel cage induction motor, but it is common practice to obtain the desired power factor for the plant, by installing a few synchronous units, or static condensers, whichever be better adapted to local conditions.

Selection of the Corrective Device.—As before stated there are two types of equipment available for correcting low power factor: synchronous condensers and static condensers.

In general, the characteristics of each type make it better suited to specific classes of service, and for every individual application one type or the other is preferable.

The choice is usually one of relative economy, although in some cases, service conditions are the determining factor, as, for example, where the requirements for mechanical drive indicate definitely synchronous condensers, or on the other hand, where provision must be made for expansion at a future time, in which case, static condensers are more suitable.

The selection for any particular application is best made by calculating the net return on the investment required for each type of equipment. This involves determining:

1. First cost:
   a. Equipment including necessary accessories.
   b. Installation expense.

2. Operating cost:
   a. Power cost (losses in equipment).
   b. Carrying charge, including maintenance, interest and depreciation.

3. Gross return:
   a. Reduction in power bill.
   b. Saving in power loss.
   c. Improvement in production due to improved voltage conditions.

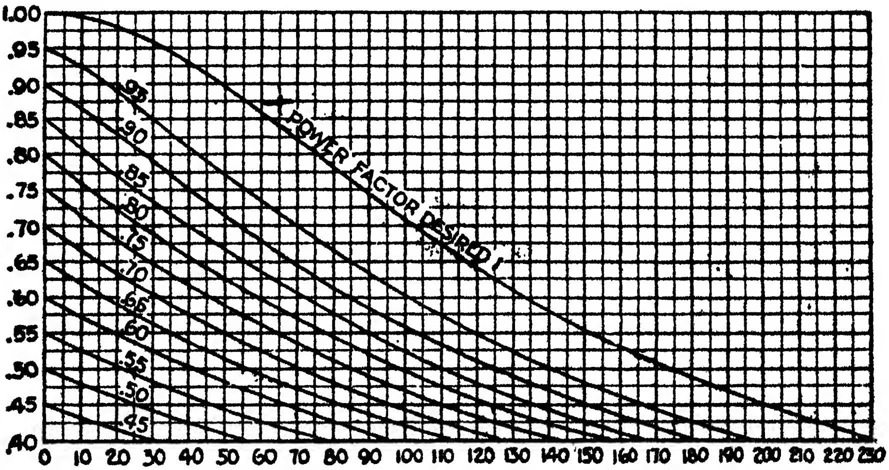


Fig. 4,254.—Curves showing determination of static condenser required to give desired correction in power factor. Follow horizontal line corresponding to present power factor of load until it intersects curve representing power factor desired. The vertical projection of this intersection on the base gives the size of condenser required in per cent of *kw*. load. *Example.*—Load 300 *kw*. Present power factor 60 per cent; power factor desired 90 per cent. Projection of intersection of 60 per cent power factor line with 90 per cent power factor curve gives desired condenser as 84.9 per cent of 300 *kw*. or 255 *kva*.

These factors all vary, most of them over a wide range, in different installations. No general rule can be given. There are, however, broad tendencies which give an idea of the general fields of application.

1. First cost:
   a. Static condenser equipments are made up of units, and therefore, the cost per *kva*. is nearly the same for all sizes. Synchronous condensers, on the other hand, cost far less per *kva*. in the large sizes than in the small sizes.

b. The unit construction of static condenser equipment affords easy handling without special equipment and with few men. The foundation required is less expensive than for the synchronous condensers, since the only requirement is to support the dead weight.

In general, from the standpoint of first cost, the static condensers show up best in the smaller sizes and the synchronous condensers in the larger sizes.

2. Operating cost:

a. The power loss in a static condenser is approximately .5% except where transformers are required, when the transformer losses, carrying from 3% in the small sizes to 2% in the large sizes, must be added. The losses in a synchronous condenser vary from 10% in the small sizes to 3½% in the large sizes. For the application under consideration, the cost of these power losses should be figured at the prevailing energy rate and for the normal hours of operation to give the total yearly cost.

b. While the attendance required for static condensers is somewhat less than for synchronous condensers, it may be assumed, with at most a small error, that a yearly charge of 15% represents a normal carrying charge for either equipment.

Here again the static condenser appears to better advantage in the smaller sizes and the synchronous condenser in the larger.

3. Gross return:

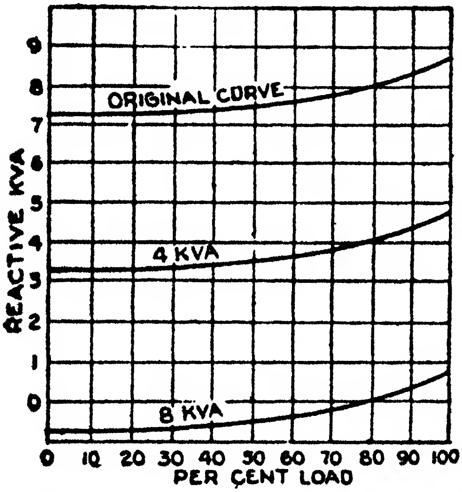
a. For each application the reduction in the yearly power bill must be determined from the anticipated load and the rate schedule in force. This item should be the same for either type of equipment.

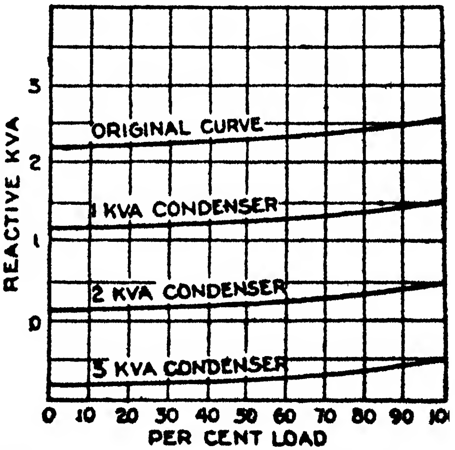
b. In some cases appreciable savings result from reduction of the line loss between the meter and the corrective equipment. Except in cases where the two types would be placed in different locations relative to the meter, this item would be the same for both.

c. Improper installation (as where load has been added without increase in the size of the transformer or of the supply wiring, or where the low tension leads are long) causes the line voltage regulation at the motor to be poor. In operations requiring frequent starting or stopping of the motor, or where the motor load varies over a wide range, this may have

a radical effect on production speed. These conditions can be improved by power factor correction through the use of either type of equipment. The only difference between the types would arise from a difference in location.

From the data secured by this method, the amount of investment required and the net return on that investment, can





Figs. 4,255 and 4,256—Westinghouse diagrams showing application of low voltage static condensers to induction motors. Fig. 4,255, results when a 4 and 8 *kva.* static condenser is used with 20 *h.p.* three phase 60 cycle, 8 pole, 220 volt squirrel cage induction motor; fig. 4,256, results when a 1, 2 and 3 *kva.* static condenser is used with a 5 *h.p.* three phase, 60 cycle, 6 pole, 220 volt squirrel cage induction motor. *Application:* Low voltage static condensers may be applied on any circuit where power factor correction is necessary, being limited only by the initial cost as compared with the initial cost of group connected 2300 volt condensers, plus transformers. The most favorable applications for low voltage static condensers are, on individual feeders, which are running hot, due to the poor power factor of the loads, and on isolated induction motors, with poor power factors.

be determined for each type of equipment. This will give a basis for determining the most economical type of equipment to use. Also, it is necessary to take into account, in addition

to the considerations of economy, the differences between the characteristics of the two types that may make one or the other better suited for use in some particular application.

Synchronous condensers provide a ready means for adjusting the amount of the corrective *kva.* in response to the changes in the load conditions, and therefore, meet some conditions of installation better than static condensers.

Static condensers usually are provided in assemblies of fixed corrective *kva.* although in the larger sizes some adjust-

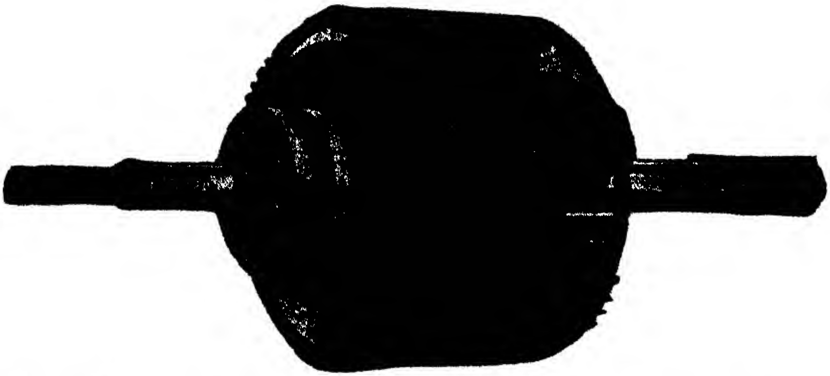


Fig. 4,257.—Field of a synchronous condenser. Note the ***amortisseur winding***, *erroneously* called ***squirrel cage winding***, consisting of two end rings which serve to short circuit spokes passing through the pole tips as shown. ***The amortisseur winding*** *assists in* ***starting*** *and serves also as a damping device to minimize* ***hunting***.

ment by comparatively wide steps can be secured. It is possible in special cases to provide for closer regulation by the addition of accessory equipment.

The function of condenser and mechanical drive can be combined in synchronous condensers, but not in static condensers.

In many cases it is an advantage to distribute the corrective *kva.* over the system in a plant, or over a large system in a city. This can be done without loss of economy through the use of static condensers, because of the uniformity of price per *kva.* and the efficiency of all sizes. Therefore, it is necessary, in any complete economic analysis involving this equipment, to have established the amount of the investment, a certain

percentage for the fixed charge, a schedule for operation, an energy rate and maintenance cost data.

Curves showing the fields of application for synchronous and static condensers are given in fig. 4,238.

Synchronous Condensers.—A synchronous motor when sufficiently excited *will produce a leading current,* that is, when over excited it acts like a great condenser, and when thus operated on circuits containing induction motors and similar apparatus for the purpose of improving the power factor it is called a *synchronous condenser.*

Although the motor performs the duty of a condenser it possesses almost none of the properties of a static condenser other than producing a leading current, and is free from many of the inherent defects of a stationary condenser.

The relation of power factor to the size and efficiency of prime movers, alternators, conductors, etc., and the value of synchronous condensers for improving the power factor is generally recognized.

Assuming that everything that is feasible has been done in applying induction motors with a view of obtaining high power factor and that the power factor is still unsatisfactory, synchronous motors, if applicable, generally prove to be the most economical and effective means of bringing about the desired improvement.

The application of synchronous motors is not so well understood as the application of induction motors, and therefore, it would be well to discuss some of the more pertinent factors regarding characteristics, fields of application, and types or lines available.

Such marked improvement has been made in the starting characteristics of synchronous motors within the past few years, that, as far as starting is concerned, synchronous motors can now be considered for any application where squirrel cage induction motors are satisfactory.

The pull-out torque of a synchronous motor varies directly with the voltage, while the maximum running torque of the induction motor varies with the square of the voltage.

Under starting conditions, however, the starting torque and pull-in torque vary with the square of the voltage, the same as with induction motors.

Synchronous motors can be designed for unity power factor current in phase with the voltage, or for leading power factor current leading the voltage.

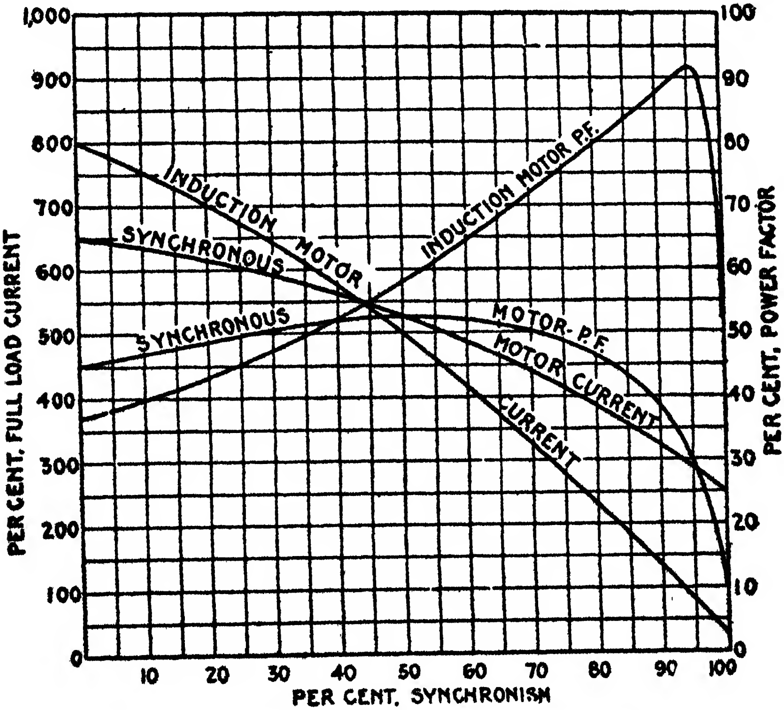


Fig. 4,258.—Comparison of the speed current curves and speed power factor curves of a typical synchronous and induction motor.

It should be understood, however, that the leading power factor synchronous motor is inherently more expensive and less efficient than the unity power factor synchronous motor, and for this reason, it is to the user's advantage to use unity power factor synchronous motors where the desired power factor improvement can be obtained by their use. The same applies to .9 power factor motors, as compared to .8 power factor motors.

It may be found that .9 power factor motors will give the desired factor improvement and the user will usually benefit by a lower price and a higher efficiency than if he had purchased a .8 power factor motor.

It is customary to operate synchronous motors with the field excitation held constant at the value corresponding to normal full rating as regards output and power factor

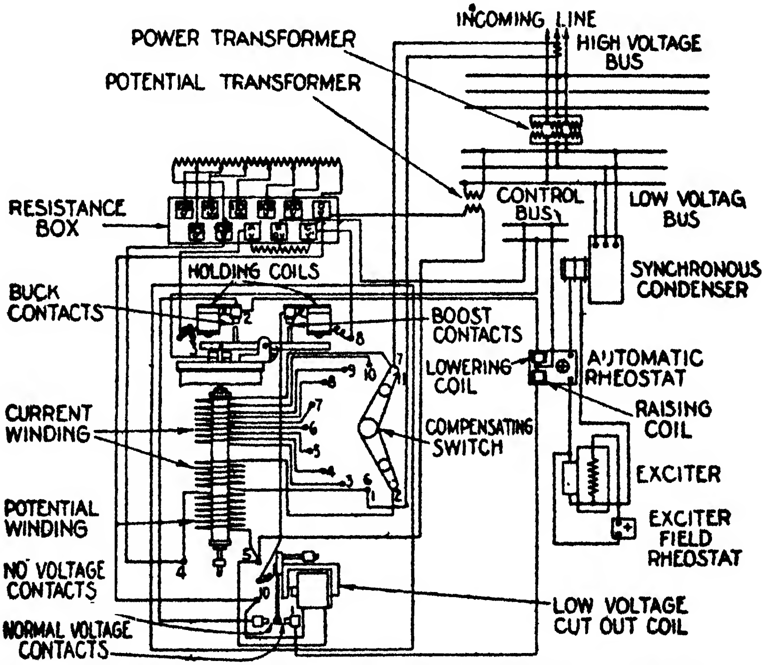


Fig. 4,259.—Wiring diagram of equipment for holding constant power factor.

Under these conditions of operation, the characteristic of the synchronous motor is such that for loads less than normal, the amount of leading reactive *kva*. available for improving the power factor is greater than at full load. This is an important asset of the synchronous motor as

NOTE.—*Synchronous condensers* should be considered for power factor improvement when the amount of leading reactive *kva*. required is 300 *kva*. or more and where this can be applied to advantage at one point. Generally speaking, static condensers can be used to better advantage where the leading reactive *kva*. required is less than 300 *kva*. There is no well defined line where static condensers should be used and where synchronous condensers should be used, and even where the capacity involved is in the order of 1000 *kva*. static condensers may suit a particular application better than a synchronous condenser while a synchronous condenser might fit another application better than the static condenser where capacities of less than 300 *kva*. are involved.

compared to the compensated or synchronous induction motor, which has a characteristic such that the leading reactive *kva*. decreases with the load.

The curves shown in fig. 4,260 illustrate what might be expected of different types of synchronous motors.

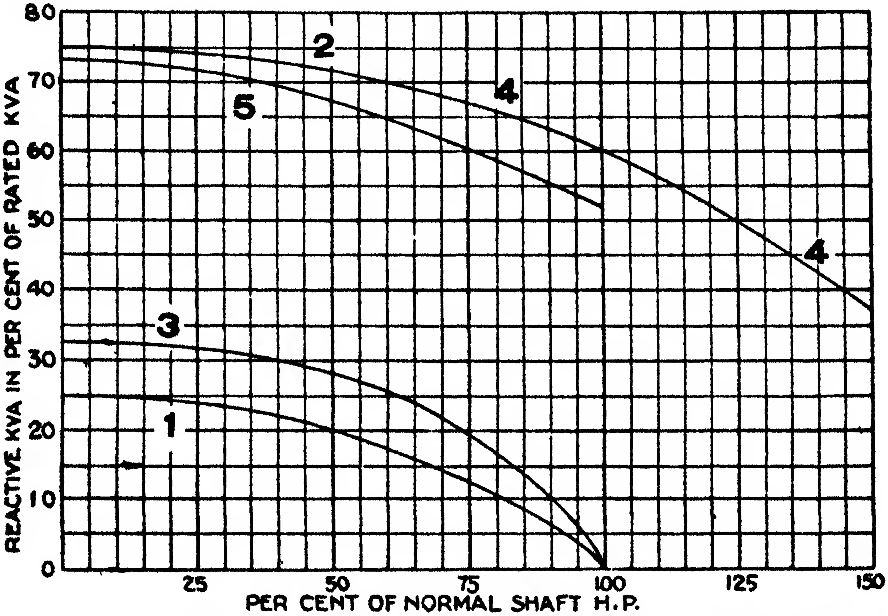


FIG. 4,260.—Curves for synchronous motors; reaction *kva*. available for power factor correction at different *h.p.* outputs. Assume motor field current is held constant at normal value. These curves are based on average values and therefore are approximate. 1, 1 *p.f.* belt driven motors; 2, .8 *p.f.* belt driven motors; 3, 1 *p.f.* air compressor motors; 4, .8 *p.f.* motors of 50% overload MG sets: 5, .85 *p.f.* motors of continuous rated MG sets.

Synchronous Condenser Calculations.—In figuring on the installation of a condenser for correcting power factor troubles, a careful survey of the conditions should be made with a view of determining just what these troubles are and to what extent

NOTE.—*The principal advantages of the synchronous condenser are:* 1, Low first cost; 2, Inherent characteristics which tend to stabilize the voltage; 3, Easy adjustment of the leading reactive *kva*. supplied; 4, Possibility of applying the synchronous condenser in conjunction with a voltage regulator to maintain constant voltage at a given point. The disadvantages as compared to a condenser are: 1, greater losses; 2, higher attendance; 3, higher maintenance costs.

they can be remedied by the presence of a leading current in the system.

It is necessary to possess a thorough knowledge of the system, covering the generating capacity in energy and *kva.*, average and maximum load, and power factor on the alternators, system of distribution, etc.

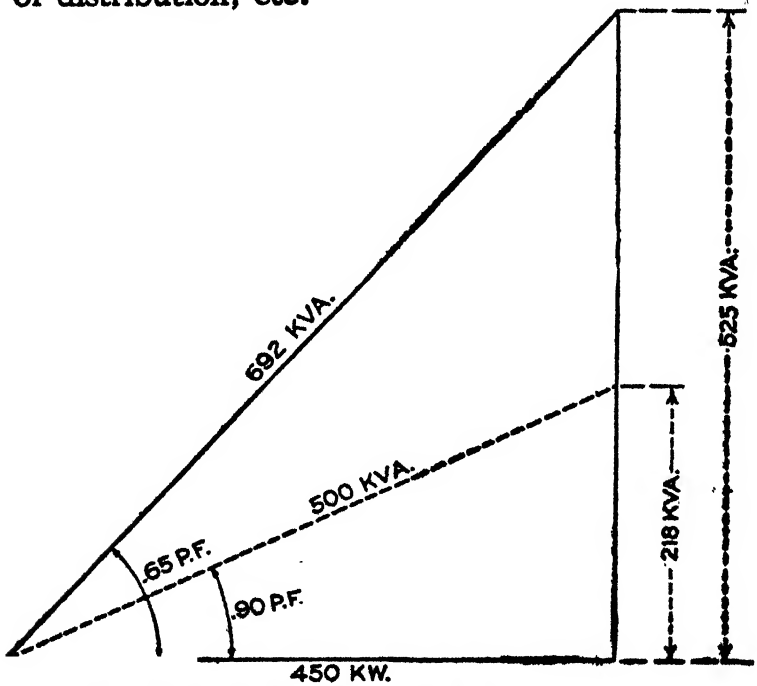


FIG. 4,261.—Diagram for synchronous condenser calculations.

The desirable location of a condenser is, of course, nearest the inductive load in order to avoid the transmission of the wattless current, but it often happens that a system is so interconnected that one large condenser cannot economically meet the conditions, in which case it may be better to install two or more smaller ones.

NOTE.—*Synchronous condensers* can be made to operate automatically, although this involves a more expensive control equipment. The big field for synchronous condensers is in main distributing substations, particularly those connected with large power systems, where it is desired to maintain voltage, and in larger industrial plants which require a considerable amount of leading reactive *kva.* and better voltage regulation.

The question of suitable attendance should also be considered and, for this reason, it may be necessary to compromise on the location.

When the location of the condenser has been decided upon and the load and power factor within its zone determined, the proper size of condenser to raise the power factor to a given value can be found in the following:

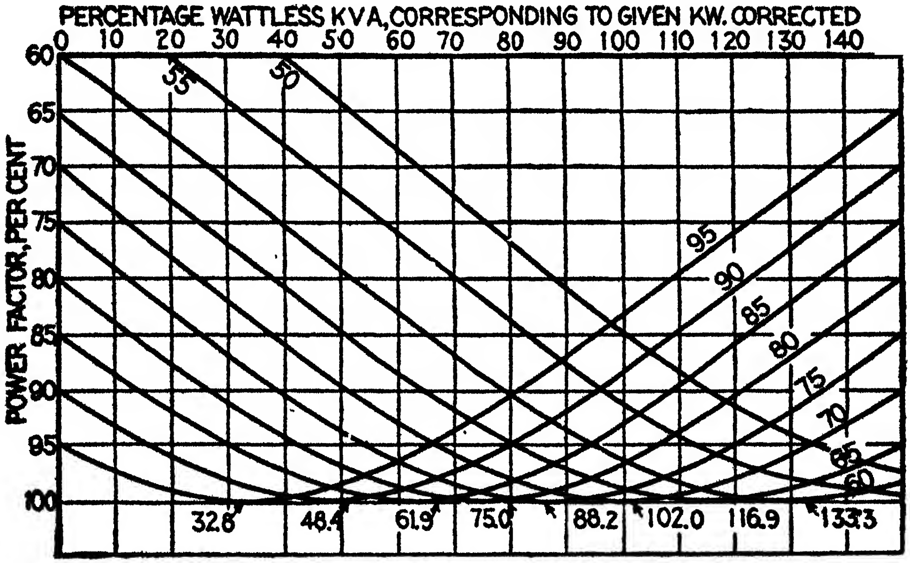


Fig. 4,262.—Curves showing amount of wattless component required to raise the power factor of a given *kw.* load to required higher value. The wattless components are expressed as percentages of the original *kw.* load. ***The numbers at the right*** which indicate the points of tangency of the power factor curves to the 100 per cent. line, show the amount of wattless component required to raise a given *kw.* load of given lagging power factor to unity power factor. Obviously the addition of further wattless component in a given case would result in a leading power factor less than unity.

Example.—Assume a load of 450 *kw.* at .65 power factor. It is desired to raise the power factor to .9. What will be the rating of the condenser?

Referring to the diagram, fig. 4,261, it is necessary to start with 450 *kw.* At .65 power factor, or 692 *kva.*, this has a wattless lagging component of $\sqrt{692^2-450^2}=525$ *kva.* With the load unchanged and the power factor raised to .9, there will be 500 apparent *kva.*, which will have a wattless component of $\sqrt{500^2+450^2}=218$ *kva.*

It is obvious that the condenser must supply the difference between 525 *kva.* and 218 *kva.* or 307 *kva.* A 300 *kva.* condenser would, therefore, meet the requirements.

If it be desired to drive some energy load with the condenser and still bring the total power factor to .9, proceed as indicated in fig. 4,263. Assume a total load of 150 *kw.* on the motor. As before, 450 *kw.* at .65 power factor, or 692 *kva.*, with a wattless component of 525 *kva.*

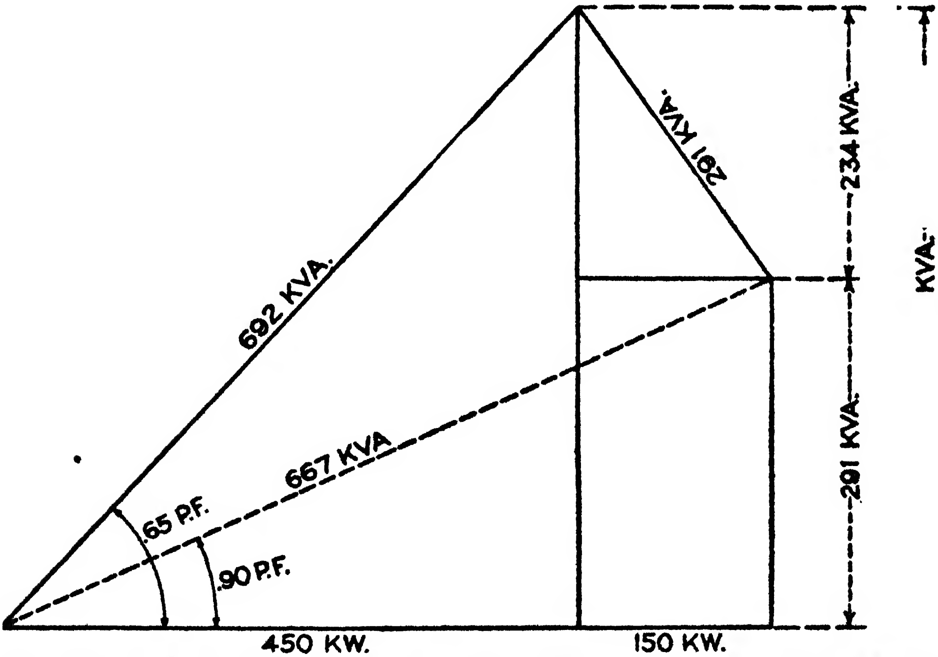


FIG. 4,263.—Diagram for synchronous condenser calculation for cases where it is desired to drive some energy load with the condenser and still bring the total power factor to .9.

NOTE.—*A desirable characteristic of the synchronous motor* is its tendency to stabilize the voltage. Under conditions of high voltage, the leading reactive *kva.* decreases and, under conditions of low voltage within reasonable limits, the leading reactive *kva.* increases. The inherent characteristics of the synchronous motor, therefore, tend to hold a constant voltage. The price of synchronous motors becomes more favorable as compared to induction motors as the ratings increase and as the speeds decrease. From a price standpoint, synchronous motors are not generally considered in ratings of less than 30 *h.p.* while for low speed applications 100 *kva.* to 400 *r.p.m.* the synchronous motor has a legitimate field regardless of the power factor problem. Since low speed induction motors have an inherently low power factor and require a large amount of lagging reactive *kva.* it is evident that the greatest benefits are obtained in power factor improvement by the use of low speed synchronous motors in place of low speed induction motors. The foregoing remarks give a general idea of the fields of application of the synchronous motor.

The energy load will be increased from 450 to 600 *kw*. as indicated, and with the power factor raised to .9 there will be a *kva*. of 667 with a wattless component of $\sqrt{667^2-600^2}=291$.

There must be supplied $525-291=234$ in leading *kva*.

The synchronous motor then must supply 150 *kw*. energy and 234 *kva*. wattless, which would give it a rating of $\sqrt{150^2+234^2}=278$ *kva*.

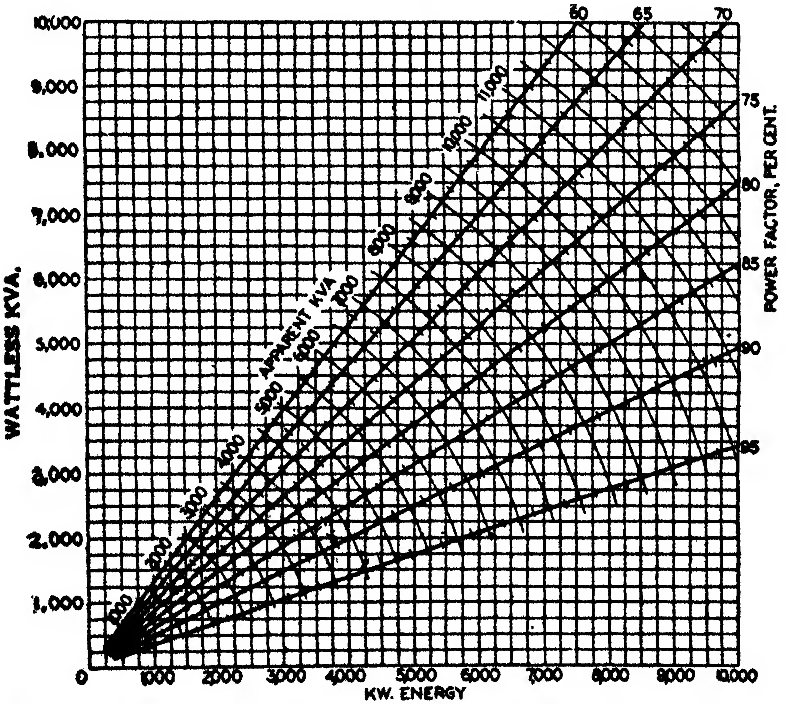


FIG. 4,264.—Chart showing the relation of energy load to apparent load and wattless components at different power factors.

The standard 300 *kva*. condenser would evidently raise the power factor slightly above .9 power factor leading.

By reference to the chart, fig. 4,264, the size of the required condenser can be obtained direct without the use of the above calculation. The method of using this chart is as follows: Assume a load of say 8,000 *kw*. at .7 power factor and that it be desired to raise the power factor to .9. Run up the vertical line at 3,000 *kw*. to the .7 power factor line, and from there along the horizontal line to the margin and find a wattless component at this power factor of 3,000 *kva*.. approximately. Again run up

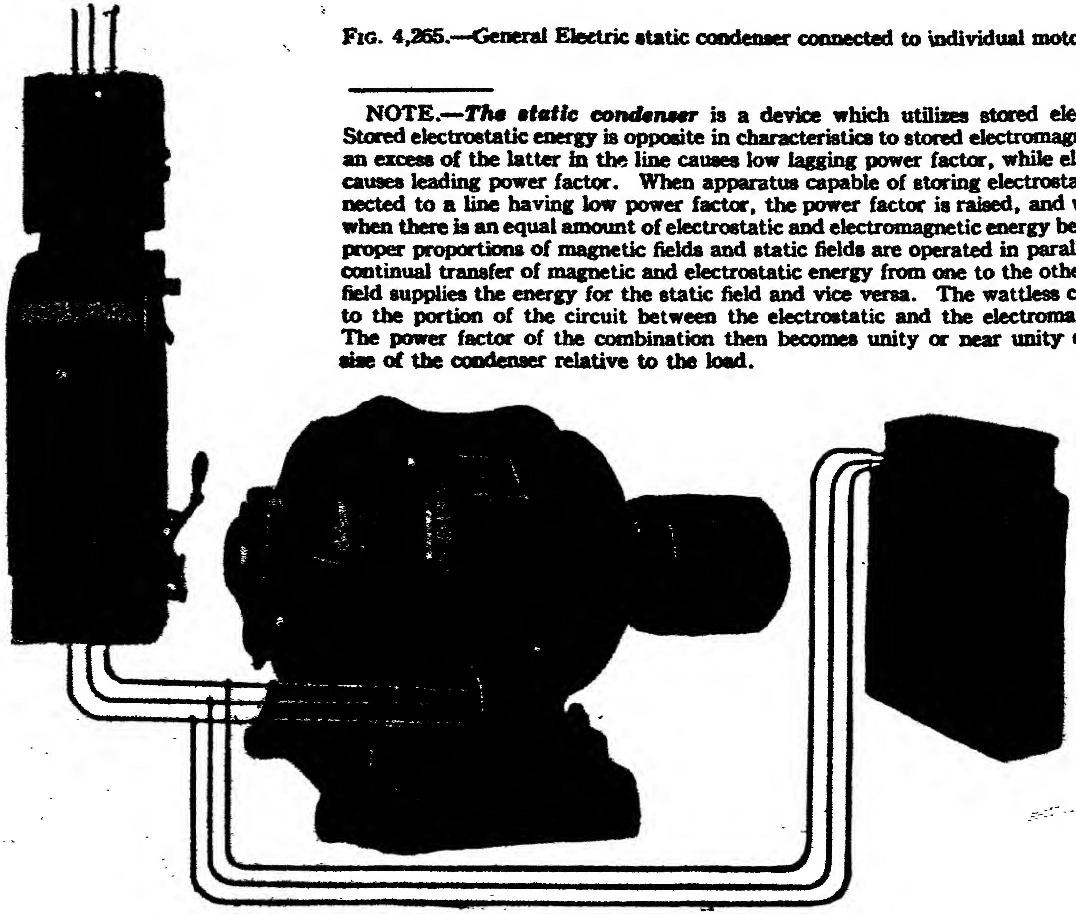


FIG. 4,265.—General Electric static condenser connected to individual motor.

NOTE.—***The static condenser*** is a device which utilizes stored electrostatic energy. Stored electrostatic energy is opposite in characteristics to stored electromagnetic energy, since an excess of the latter in the line causes low lagging power factor, while electrostatic energy causes leading power factor. When apparatus capable of storing electrostatic energy is connected to a line having low power factor, the power factor is raised, and will become 100% when there is an equal amount of electrostatic and electromagnetic energy being stored. When proper proportions of magnetic fields and static fields are operated in parallel there follows a continual transfer of magnetic and electrostatic energy from one to the other. The magnetic field supplies the energy for the static field and vice versa. The wattless current is confined to the portion of the circuit between the electrostatic and the electromagnetic apparatus. The power factor of the combination then becomes unity or near unity depending on the size of the condenser relative to the load.

the 3,000 *kw*. vertical line to the .9 power factor line and from there along the horizontal line to the margin and find a wattless component of 1,500 *kva*. The rating of the condenser will then be 3,000 *kva*.−1,500 *kva*.= 1,500 *kva*. This table of course can be used for hundreds of kilowatts as well.

For determining the rating of a synchronous motor to drive an energy load this chart is not so valuable, although it can be used .. determining the wattless component direct in all cases where the energy component and power factor are known. Knowing this energy component and power factor or wattless component, the energy load can obviously be found by referring to the curved lines on the chart, the curve that crosses the junction of the vertical energy line and the power factor or wattless component line giving the total apparent *kva*.

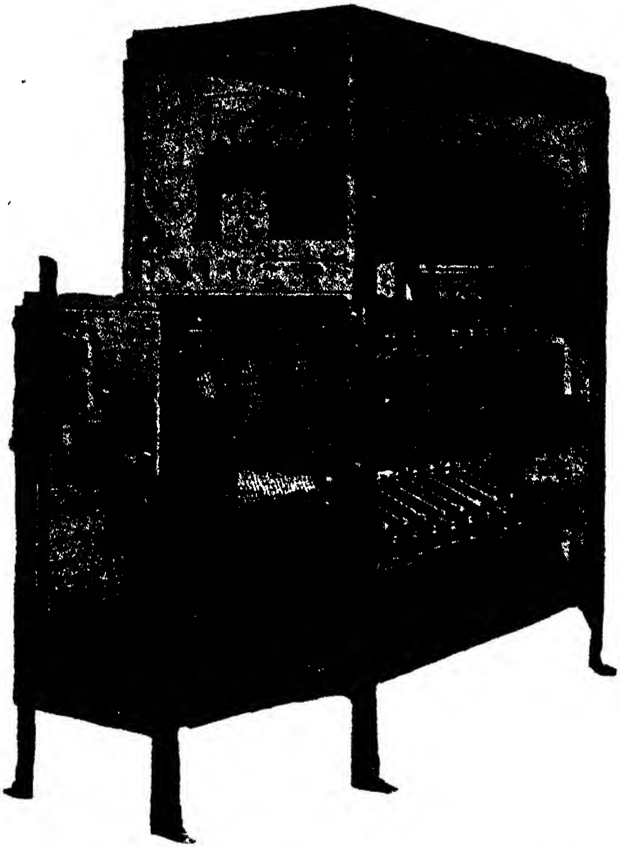
Static Condensers.—By definition a static condenser is *a device that stores up electrostatic energy by subjecting the insulation or the dielectric, between two conducting elements, to a voltage stress.*

When the voltage applied to a condenser is increasing, energy is being stored, and when the voltage is decreasing, energy is being returned to the circuit. When an inductance is connected to the line, electromagnetic energy is stored, but this storage of energy takes place at a different time from that of electrostatic energy.

The current taken by a perfect inductance is 90° lagging, while the current taken by a perfect condenser is 90° leading. The static condenser therefore acts as a storage tank, receiving the electro-magnetic energy as it is returned to the line and supplying it back to the motor as needed, thus confining the wattless current to the portion of the line between the condenser and the load, and avoiding its transmission over the line. The power factor of the line between the condenser and the load, and the power factor of the load remain unchanged. None of the operating conditions of the motor are changed, other than a possible improvement in performance, due to better voltage regulation being maintained at the terminals of the motor. Synchronous condensers have played an important part in this field, but their use is somewhat restricted to plants where they are needed in large sizes and where the attention necessary to rotating apparatus is not a serious factor.

In order to meet the demand for corrective devices for smaller loads and to eliminate the high cost of installation and

attendance, the static condenser has been developed. Other advantages that may be mentioned are:



1. No attendance is required.

2. No special foundation is required.

FIG. 4,266.—General Electric three phase static condenser. For 2,300 volt service it consists of a number of static condenser units, a reactance for dampening out the higher harmonics in the voltage wave which would affect the corrective capacity of the units, a discharge resistance for draining the static condenser charge when disconnected from the line, and an oil circuit breaker for the control of the equipment. For 220, 440 and 550, volt service, transforming apparatus is also provided, to step up the supply voltage to 1,200 volts for the static condensers. The number of static condenser units included in an equipment is directly proportional to the capacity required. The units are treated under vacuum to withdraw all moisture, immersed in oil, and the container then hermetically sealed to prevent possible absorption of moisture from the air. The units are mounted on a rack as shown in the illustration. They are connected in parallel across each phase, one terminal being connected directly to one leg while the other is connected to the other leg of the phase through a fuse. The purpose of the fuse is twofold. First, to provide protection for the units against the application of an abnormal voltage; second, to provide a means of automatically opening the connection of any unit to the bus on the rack in case of failure of the unit, making it unnecessary to disconnect the entire equipment.

3. Has no moving or wearing parts requiring replacement.

4. Condenser does not "drop off" the line if the voltage fail for a short time.

5. Noiseless in operation.

***Construction of Static Condensers.**—Static condensers are made in units containing *systems of metal plates separated by dielectric material*, so that energy is stored by the application of voltage to the plates.

In order to conveniently subject the dielectric material to uniform voltages, it is divided into many sheets spaced with metal foil, alternate layers of metal foil being connected together to form terminals.

Various numbers of sheets are used between the foil depending on the voltage. The *kva.* capacity of a given condenser is a function of the area of dielectric material and the voltage per unit thickness applied to this material.

The working voltage per unit thickness has been determined by long investigation. Static condensers are designed for indoor and for outdoor service. The outdoor condensers are enclosed in a weather protected housing.

Calculations for Static Condensers.—The *kva.* of static condensers required to correct any given power factor to any desired power factor is *entirely dependent on the kw. load of the plant.*

A condenser which would correct a 100 *kw.* load from 50% power factor to unity power factor would only increase the power factor to 76% if the *kw.* load became 200.

Example—An industrial plant has an average load of 100 *kw.* and average power factor 45%. The power rates are such that a penalty is imposed for power factors below 85% and the penalty is sufficient to warrant the installation of power factor correcting apparatus; that is, the annual saving by correcting the power factor should more than offset the interest, upkeep and depreciation of such equipment.

*NOTE.—This description relates to Westinghouse type LD static condenser for power factor correction on 60 cycle circuits.

Example.—Present load $=100$ *kw.* at 45% power factor. Desired power factor $=85\%$.

Present *kva.* $=\frac{100}{.45}=222$ *kva.*

Present reactive *kva.* $=\sqrt{222^2-100^2}=198$ *kva.*

Kva. at desired power factor $=\frac{100}{.85}=117.8$ *kva.*

Reactive *kva.* at desired power factor $=\sqrt{117.8^2-100^2}=61.6$ *kva.*

Corrective effect needed $=198-61.6=136.4$.

Size of standard condenser $=150$ *kva.*

FIG. 4,267.—Diagram for power factor correction as explained in the accompanying example.

In some cases it may prove profitable to correct the power factor up to unity, but in the present case all that is desired is to correct the power factor to 85%. At 45% power factor the total *kva.* is 222 and accordingly the power transformer must be sufficiently large to take care of it.

The reactive, or wattless *kva.* is the vector difference between 222 and 100 or 198 *kva.*

At 85% power factor the total *kva.* will be 117.8 which shows that the customer's transformer capacity can be practically cut in half. The wattless *kva.* in this case will be 61.6 so that the necessary corrective effect to change the load from 45% to 85% power factor will be 198 minus 61.6 or 136.4 *kva.* The proper size of static condenser would, therefore, be one of a 150 *kva.* rating. Obviously the new power transformer rating

Power Factor Correction Table

Kw. Load	Original Power Factor %	Kv-a. of Condenser to Raise to 85%	Variations in Power Factor (%) with Change in Load, the New Load Having the Same Power Factor without Condenser. 50 Kw.	75 Kw.	100 Kw.	125 Kw.	150 Kw.
100	40	167.3	68*	99.9*	85	72	66
100	45	136.8	81*	99.8	85	74	68
100	50	115	90*	97	85	77.5	72
100	55	90	96*	95	85	78	73.9
100	60	71	99*	93.5	85	79	76
100	65	55	99.5	92	85	81	78
100	70	40	97.7	90	85	82	79.5
100	75	26	94	88	85	83	81.5
100	80	13	89.5	86.5	85	84	83.5
100	85	0	85	85	85	85	85

*Leading power factor.

should not be less than 150 *kva.* which is the continuous demand of the static condenser alone.

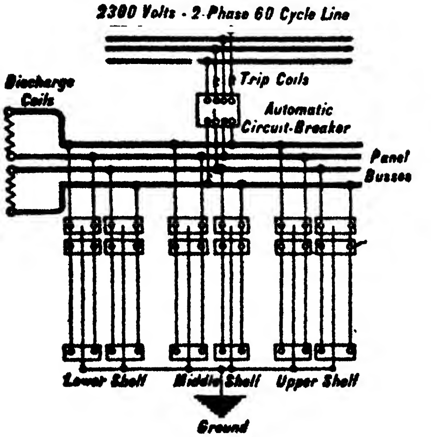
When the condenser *kva.* has been determined for a given condition, the power factor correction will change as the load changes. The load may change by addition of motors or by increase of the load on the motor already in operation. The change in the latter case is dependent upon the characteristics of the motor. When the load is changed by the addition of motors having the same power factor as the first one, the conditions will change according to the table here given.

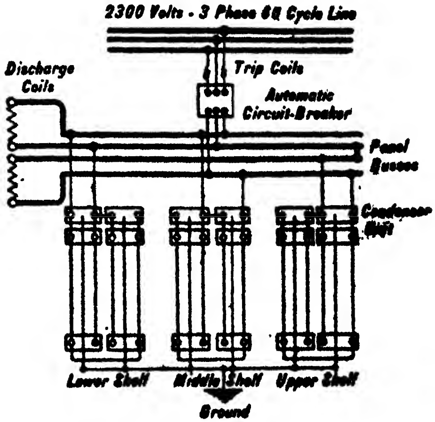
Example.—Assume a plant with thirty motors of five *kw.* each, all having a power factor of 50% when running. On an average but twenty of these motors are in operation at one time giving a load of 100 *kw.* at 50% power factor. To correct this load to a power factor of 85%, 115 *kva.* of condenser is required. When occasionally, all thirty motors are running, the load will be 150 *kw.* and the power factor will then drop to 72% and when but ten are in operation, the power factor will become 90% leading.

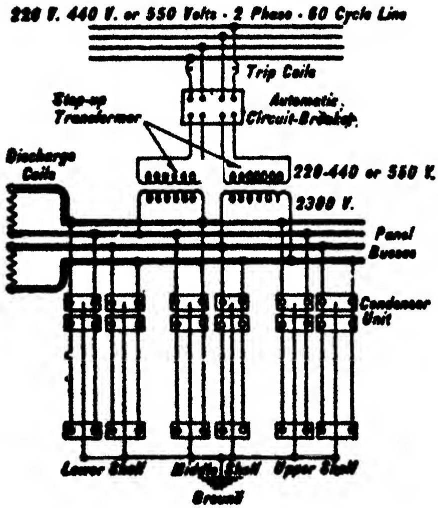
Data Required for the Application of Static Condensers.—In contemplating the installation of a

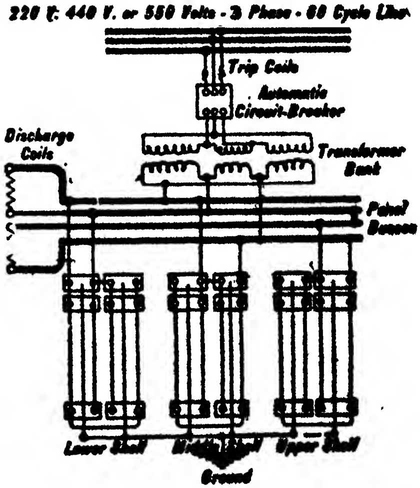
static condenser, the following information should be obtained:

1. Present load in *kw.*;
2. Present power factor;
3. Desired power factor;









FIGS. 4,268 and 4,269.—Wiring diagrams for 2,300 volt static condensers. Fig. 4,268, two phase; fig. 4,269, three phase.

FIGS. 4,270 and 4,271.—Wiring diagrams for 220, 440 or 550 volt static condensers using *transformers*. Fig. 4,270, two phase; fig. 4,271, three phase.

4. Actual average voltage in plant;

5 Maximum sustained voltage for periods of at least one half hour;

6. Frequency and number of phases;

7. Rating of the power transformers;

8. Is the plant at the end of a long feeder or is it located near the center of an industrial district?

9. Is any future increase over the present load contemplated and if so how much?

10. Are there any machines, such as compressors, in the plant to which synchronous motors can be properly applied?

11. Does the plant operate at normal capacity twenty-four hours a day? If not, what are the load conditions during the night?

12. Is the load subject to seasonal changes and if so to what extent?

13. What is the approximate short circuit current possible at the point where the static condenser is to be connected?

This information is necessary for the selection of the circuit breaker.

For long lines, where charging current is a factor at light loads, the static condenser can be divided into two sections with one unit installed at the receiving end of the line and the other at the generating end.

Thus the charging current of the line through the static condenser at the generating end gives a drop in voltage equivalent to the rise in voltage over the inductance of the line.

In case there be branch circuits tapped from the line, the total capacitance may be split up into sections located just ahead of each tap off point to hold the voltage at these points at a pre-determined value. Furthermore, the stability of a long transmission line can be materially increased by the installation of a series static condenser because its compensation

NOTE.—*Control apparatus required for static condensers.* No additional switches or protective devices are required where the individual static condenser is connected directly to the motor terminals, inside the motor and protective device, since it is protected by the motor control device and discharges through the motor windings when the motor line is opened The combination of a static condenser and squirrel cage induction motor makes an exceedingly satisfactory high power factor unit. Its price generally is less than that of a synchronous induction motor. The unit is much more efficient than a synchronous induction motor and in strength, simplicity, ease of operation, and maintenance cost is superior to all other motors. Where atmospheric conditions preclude the use of motors with collector rings, the squirrel cage motor with a static condenser is particularly adaptable.

of the inductive reactance enables a greater load to be carried over the line before the load limit is reached.

The application of static condenser equipment to overhead lines of low voltage is equally attractive. Heretofore, very little improvement in voltage regulation was obtained by increasing the size of conductors

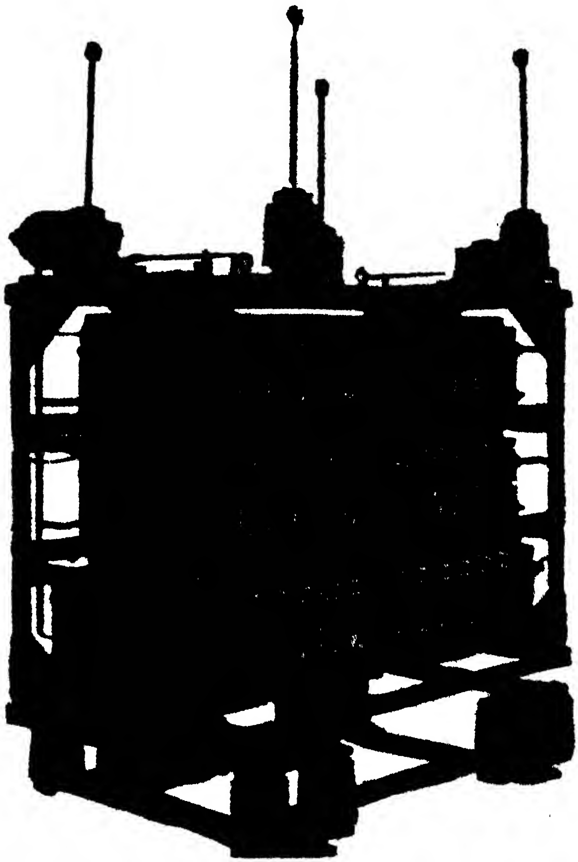
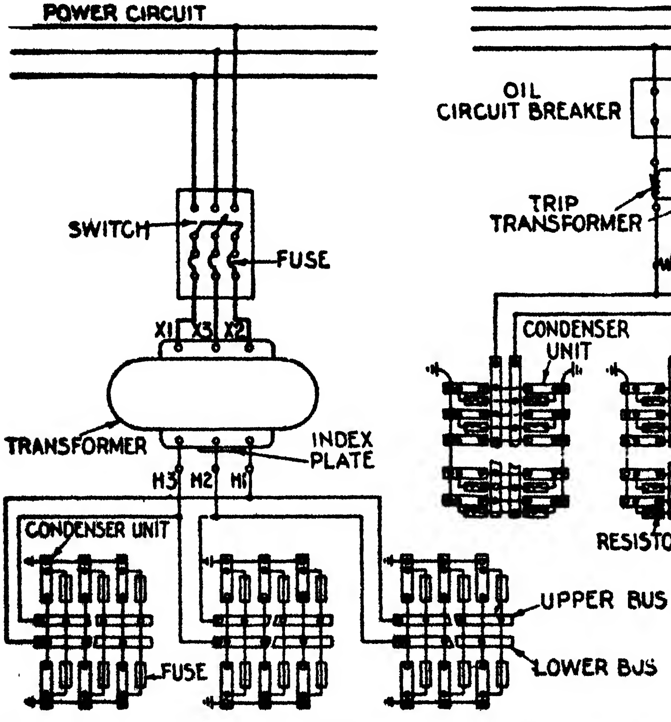


FIG. 4,272.—Internal assembly of General Electric 415 *kva.*, 3,170 volt single phase series static condenser mounted on insulating rack for 33 *kva.* line voltage.

beyond a certain limit, because the controlling factor was the inductive reactance of the line. With the addition of a static condenser, however, the copper may be increased in size until the economic limit of copper is reached. Thus it is possible to use low cost line construction in supplying large rural sections with electric power.

Series Static Condenser.—The use of a series static condenser, that is, ***a static condenser in series with a transmission line to compensate for transmission line reactance*** is a new advance in electrical engineering, for the practical application of such a static condenser has presented problems that, until recently, had been unsolved.



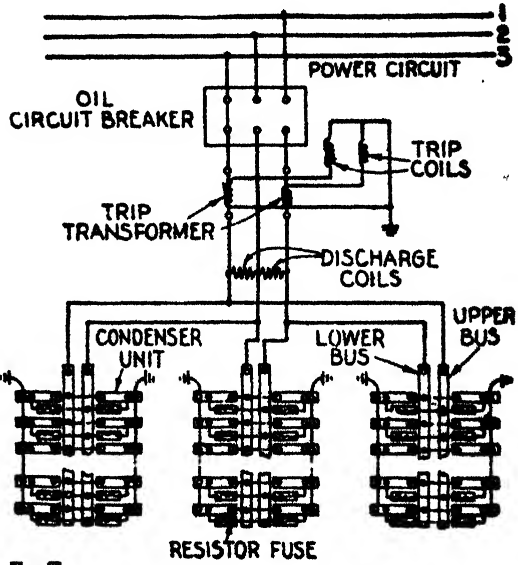


FIG. 4,273.—Connections for 3 phase 220 volt static condenser with transformer. If the units were designed for direct installation on circuits of this voltage a considerably greater active area would have to be provided in order to handle the increased current and this would result in increased cost.

FIG. 4,274.—Connections for 3 phase 2,300 volt static condenser with resistor fuse.

A static condenser can be selected that will compensate for the inductive reactance of the line and transformers in the transmission circuit in which it is connected. In this manner,

the over all voltage characteristics can be made to approximate those which would exist if resistance only were present.

Figuratively, the static condenser ***eliminates the element of distance in power transmission*** and gives the same voltage condition at the receiving end of the line as if the alternator were directly connected to the receiver bus, except of course, for the effect of line resistance. The magnitude of the line current is not changed. Thus, by utilizing a static condenser, approximately the characteristics of *d.c.* transmission can be obtained and the advantages of the *a.c.* system retained. For short lines, the static condenser can be located at any point in the line with the same net over all results.

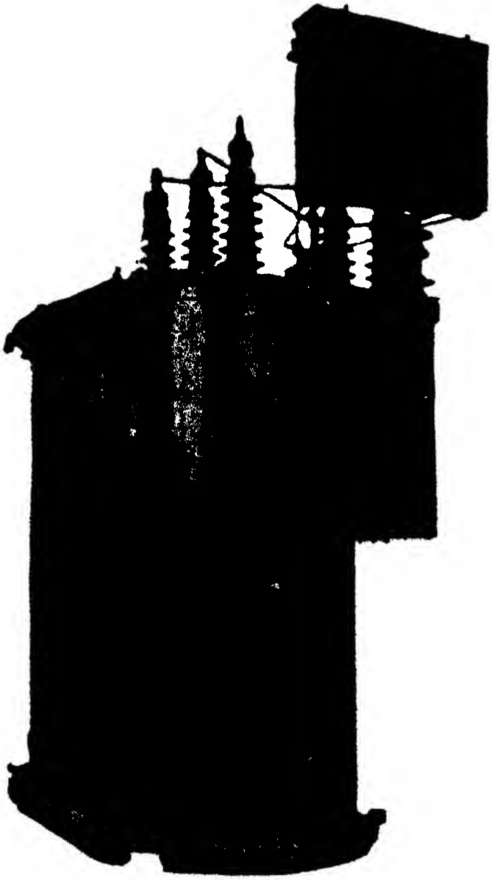


FIG. 4,275.—General Electric single phase. assembly of a series static conde

TEST QUESTIONS

1. *What is a condenser?*
2. *What is the effect of induction, and of capacity in a circuit?*
3. *What effect has an induction motor on the circuit?*
4. *What happens with a low, lagging power factor?*
5. *Describe the effect of fully loaded and lightly loaded induction motors on the power factor.*
6. *What is the advantage of improving the power factor?*
7. *What is the cause of low, lagging power factor?*
8. *How is the power factor improved?*
9. *Name two kinds of condensers used to improve the power factor.*
10. *What governs the choice between synchronous and static condensers?*
11. *Describe in detail the synchronous condenser.*
12. *Which is the more expensive and less efficient, a condenser designed for unity power factor, or leading power factor?*
13. *How is the field excitation regulated by synchronous motors?*
14. *Explain in detail synchronous condenser calculations.*
15. *What is a static condenser?*
16. *Give calculations for a static condenser and describe its construction.*

17. *What data is required for the application of static condensers?*

18. *What is a series static condenser?*

19. *Explain the application of a series static condenser.*

CHAPTER 79

A. C. Voltage Regulators

Voltage regulation is one of the important factors in providing satisfactory electrical service, the aim of every utility company. It presents a vital problem, both to the engineer who designs, as well as to the one who operates the system.

While high efficiency in the conversion of energy in the coal or waterfall to electric power is essential for the economical operation of the plant, it is in many ways secondary in importance to the voltage regulation of the system, as poor voltage regulation affects the quality of service and may seriously impair its commercial value.

Some of the results of poor voltage regulation may be: low candle power, or high lamp breakage; insufficient development of heat in electric household appliances; the capacity, speed, temperature, and starting torque of motors may be affected and otherwise unsatisfactory service may become a burden to the apparatus and to the patience of those depending on it. Maintenance of voltage at its normal value by automatic induction voltage regulators not only corrects these conditions and improves the service rendered the consumer, but makes it possible for the utility company to effect economies in the operation of the system, and to derive the revenue anticipated at the time the system was laid out.

Voltages higher than normal result in increased transformer core losses and increased lamp renewals.

Voltages lower than normal result in revenue losses and dissatisfied customers.

Close voltage regulation, not only permits the utility company to provide satisfactory service for the consumer, but it also makes possible economies in operation which would otherwise be unattainable.

Electric appliances used in the household are designed for most efficient

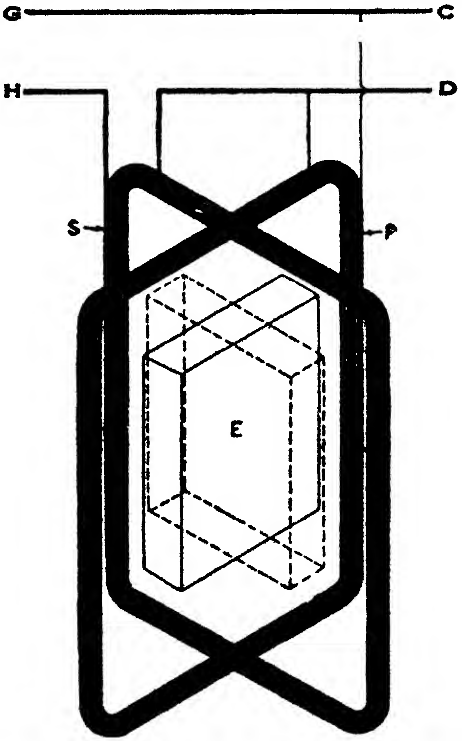


FIG. 4,276.—Diagram *illustrating the principle of induction voltage regulators. The primary coil* P, *consisting of many turns of fine wire*, is connected across the main conductors C and D, coming from the alternator. *The secondary coil* S, *consisting of a few turns of heavy wire*, is connected in series with the conductor D. The laminated iron core E, mounted within the coils, is capable of being turned into the position shown by the dotted lines. When the core is parallel with coil P, the magnetic lines produced in it by the primary coil, induce a pressure in the secondary coil which aids the voltage; when turned to the position indicated by the dotted lines, the direction of the magnetic lines of force are reversed with respect to the secondary coil and an opposing pressure will be produced therein. Thus, by turning the core, the pressure difference between the line wires G and H, can be varied so as to be higher or lower than that of the main conductors C and D. Regulators operating on this principle may be used for *theatre dimmers*, as controllers for series lighting, and also to adjust the voltage or the branches of unbalanced three wire single phase and polyphase systems.

operation at a definite predetermined voltage. Their operation at a voltage other than normal impairs the service, increases the cost to the consumer, and reduces the revenue to the operating company.

A large per cent of the regulators now in use are for the automatic voltage control of feeder circuits taking power from bus bars having practically constant voltage.

The regulator is used to automatically increase or decrease the voltage of the outgoing feeder so as to compensate for the variable line drop or variable bus voltage and thus maintain a constant voltage at the center of distribution of the particular feeder.

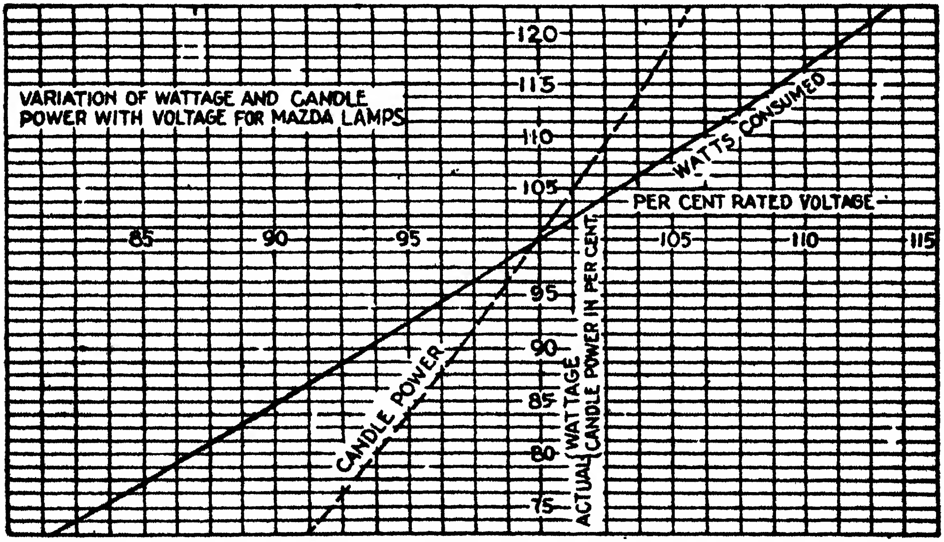


FIG. 4,277.—Curves showing variation of wattage and candle power with voltage for Mazda lamps. The curves show that a slight variation in voltage seriously affects the performance of the lamp. *For example*, a 2% drop reduces the candle power to 93½% of normal and the wattage to 96½% of normal.

Regulators.—In supplying lighting systems, where the load and consequently the pressure drop in the line increases or decreases, it becomes necessary to raise or lower the voltage of an alternating current, in order to regulate the voltage delivered at the distant ends of the system. This is usually accomplished by means of an *alternating current regulator*.

There are two types of voltage regulator:

1. Induction regulator.
2. Load ratio control transformers.

Ques. Of what does an induction regulator consist?

Ans. It consists of a primary winding or exciting coil, a secondary winding which carries the entire load current.

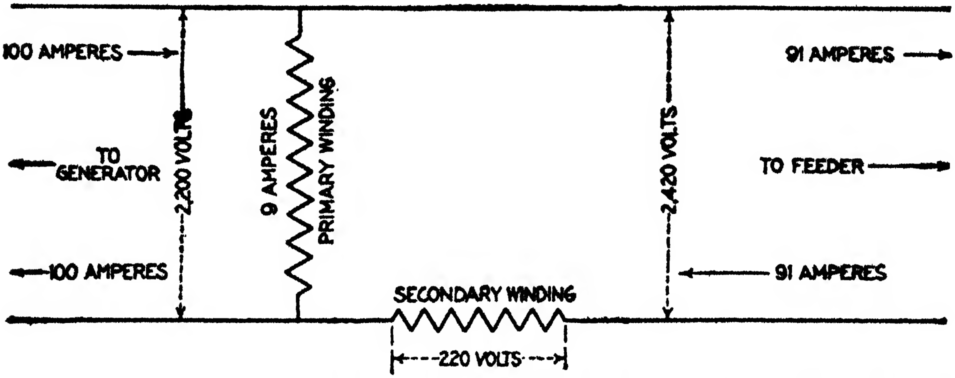


FIG. 4,278.—Diagram of induction regulator *raising the voltage* 10%. *In the diagram* an alternator is supplying 100 amperes at 2,200 volts. The regulator raises the feeder pressure to 2,420 volts, the current being correspondingly reduced to 91 amperes, the other 9 amperes flowing from the alternator through the primary of the regulator, back to the alternator.

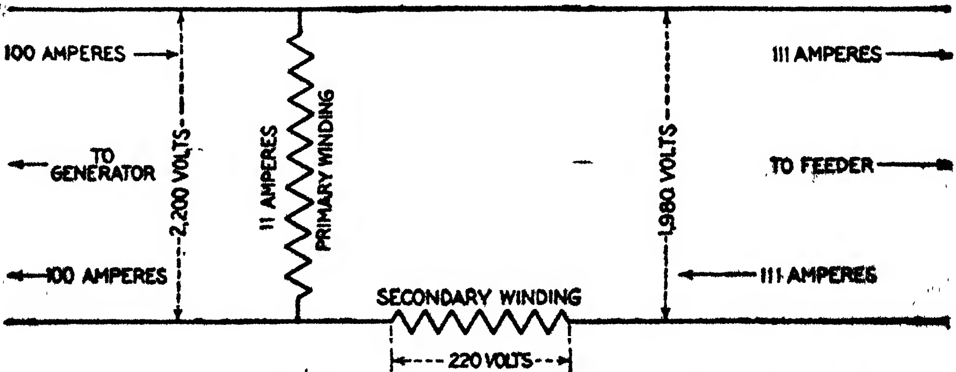


FIG. 4,279.—Diagram of induction regulator *lowering the voltage* 10%. *The diagram shows* the regulator lowering the feeder pressure to 1,980 volts with an increase of the secondary current to 111 amperes, the additional 11 amperes flowing from the feeder, through the primary back to the feeder.

Ques. What is its principle of operation?

Ans. When the primary coil is turned to various positions the magnetic flux sent through the secondary coil varies in value, thereby causing corresponding variation in the secondary voltage, the character of which depends upon the value and direction of the flux.

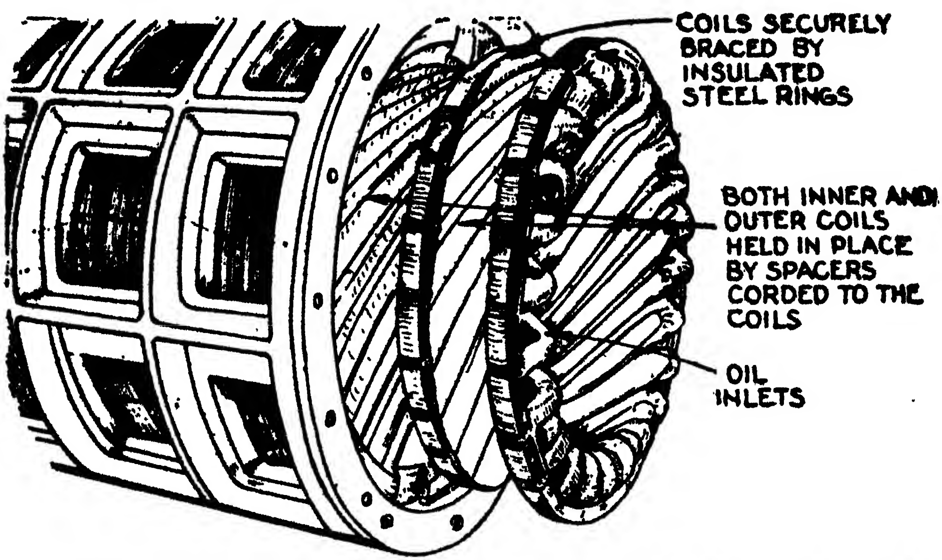


FIG. 4,280.—General Electric induction voltage regulator construction 1. View showing bracing of *stator* coils on polyphase regulators.

Ques. What is the effect of turning the secondary coil to the neutral position at right angles with the primary coil?

Ans. The primary will not induce any voltage in the secondary, and accordingly it has no effect on the feeder voltage.

Ques. What are the effects of revolving the primary coil from the neutral position first in one direction then in the other?

Ans. Turning the primary in one direction increases the voltage induced in the secondary, thus increasing the feeder voltage like the action of a booster on a direct current circuit while turning the primary in the opposite direction from the neutral position, correspondingly decreases the feeder voltage.

Ques. It was stated that for neutral position the primary

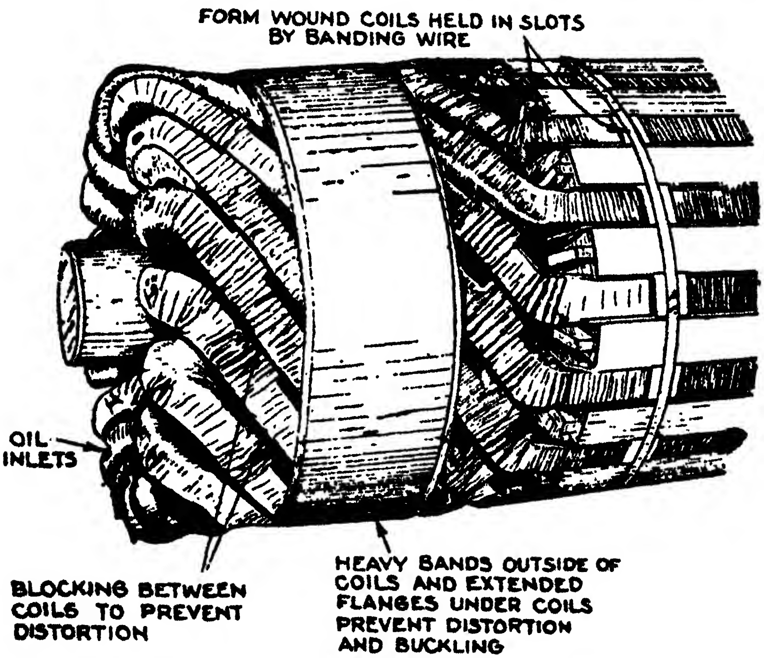


FIG. 4,281.—General Electric induction voltage regulator construction 2. View bracing of *rotor* coils on polyphase regulators.

had no effect on the secondary; does the secondary have any effect on the feeder voltage?

Ans. The secondary tends to create a magnetic field of its own self-induction, and has the effect of a choke coil.

Ques. How is this tendency overcome?

Ans. The primary is provided with a short circuited winding, placed at right angles to the exciting winding.

In the neutral position of the regulator, this short circuited winding acts like the short circuited secondary of a series transformer, thus preventing a choking effect in the secondary of the regulator.

Ques. What would be the effect if the short circuited winding were not employed?

Ans. The voltage required to face the full load current through the secondary would increase as the primary is turned away from either the position of maximum or minimum regulation, reaching its highest value at the neutral position.

The short circuited winding so cuts down this voltage of self-induction that the voltage necessary to force the full load current through the secondary when the regulator is in the neutral position is very little more than that necessary to overcome the ohmic resistance of the secondary.

Ques. What effect is noticeable in the operation of a single phase induction regulator?

Ans. It has a tendency to vibrate similar to that of a single phase magnet or transformer.

Ques. Why?

Ans. It is due to the action of the magnetizing field varying in strength from zero to maximum value with each alteration of the exciting current, thus causing a pulsating force to act across the air gap, which tends to cause vibration when the moving part is not in perfect alignment.

Methods of Operation.—Induction voltage regulators may be operated by hand, either directly or through a sprocket wheel and chain, by a hand controlled motor, or automatically.

If motor operated with hand control, the motor may be of the single phase *a.c.* type, although the polyphase *a.c.* motor is preferred.

If automatically operated, it is even more advisable to use the polyphase type, as the single phase motor is not well adapted for this purpose, since, for the same characteristics, the armature of a single phase motor has approximately twice the weight and twice the inertia of an armature of a polyphase motor. This increases the over running of the regulator and also its tendency to hunt. Furthermore, the commutator and brushes of a single phase motor require considerable attention.

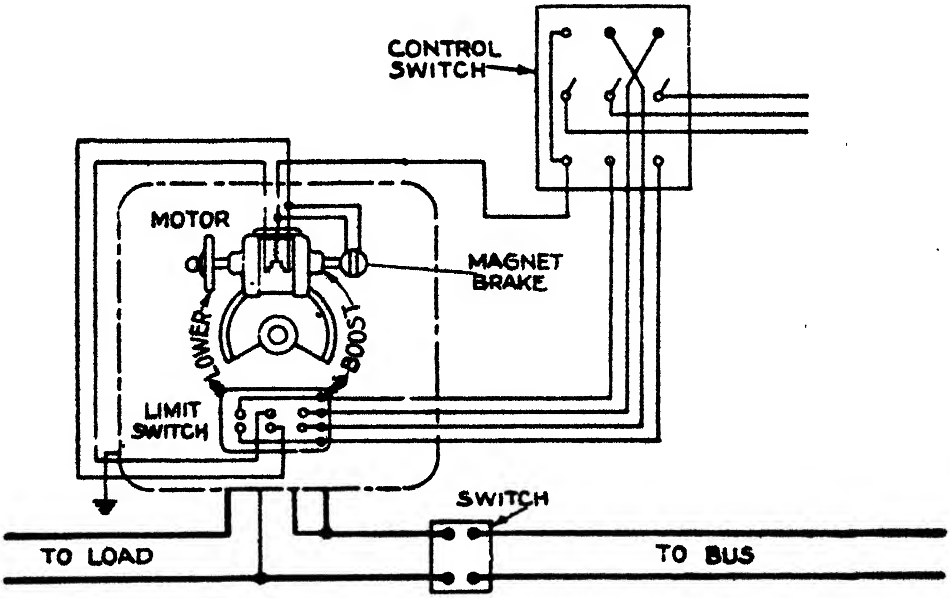


FIG. 4,282.—General Electric connection diagram for motor operated feeder induction voltage regulator using three phase operating motor.

When the regulator is motor operated, the motor is controlled by means of a small triple pole, double throw switch mounted on the switchboard or in any other convenient location. Closing the switch one way or the other will start the motor so as to operate the regulator to permit raising or lowering the line voltage as may be desired. When the correct line voltage is obtained the regulator may be stopped by opening the switch.

A limit switch is provided which stops the movement of the regulator by opening the motor circuit as soon as the regulator has reached either extreme position, but which automatically closes this circuit again as soon

as the regulator armature recedes from the extremė position. The operation of the switch in either limit position does not interfere with the movement of the regulator in the opposite direction, which movement the operator may produce by reversing the controlling switch.

All induction regulators for motor or automatic operation are provided with a brake to stop the motor as soon as the voltage has been properly adjusted.

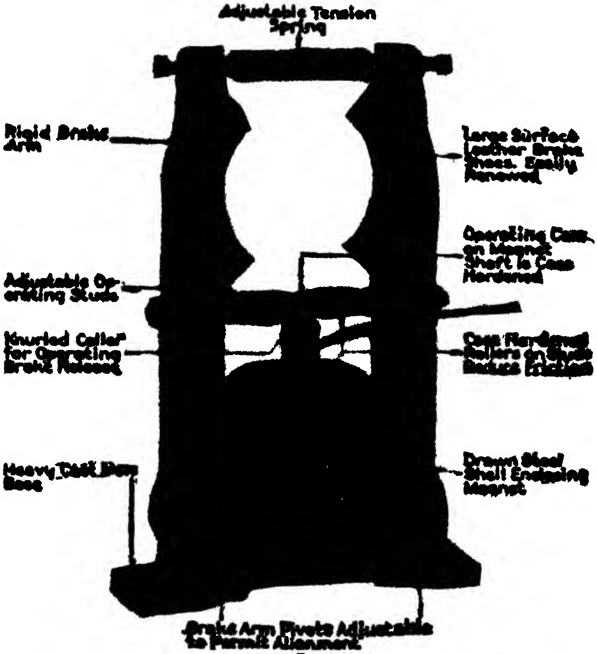


FIG. 4,283.—General Electric torque motor brake for motor operated automatic induction voltage regulator, station type.

This brake for all standard sizes is the magnetically released type which is noiseless in its operation and prevents any other running of the motor. The brake pressure is released simultaneously with the closing of the operating motor circuit, consequently releasing the motor from any load due to braking action. The opening of the motor circuit applies the brake, preventing any further operation of the adjusting mechanism after the proper voltage has been obtained. A diagram of the connections for a single phase regulator operated by a hand controlled three phase motor is shown in fig. 4,282. Not only are the connections for the regulator,

indicated, but also the connections for the motor, limit switch, and for the reversing switch controlling the motor.

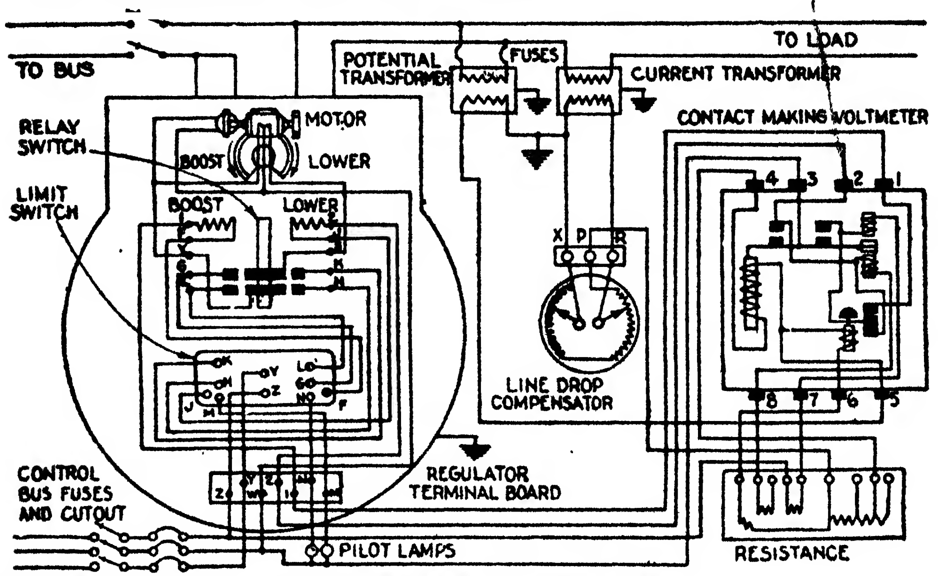


FIG. 4,284.—Connections for operation of a single phase regulator.

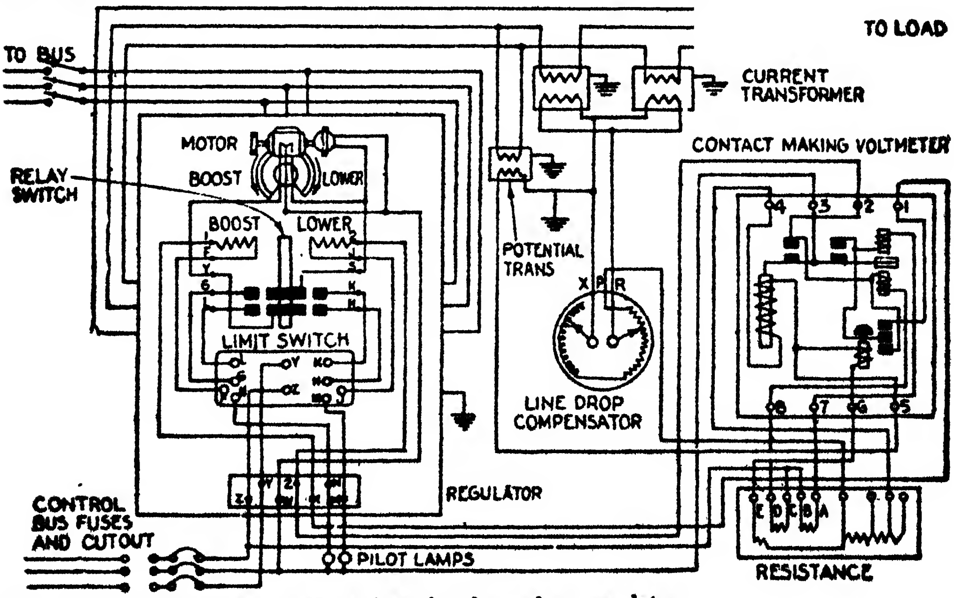


FIG. 4,285.—Connections for operation of a three phase regulator.

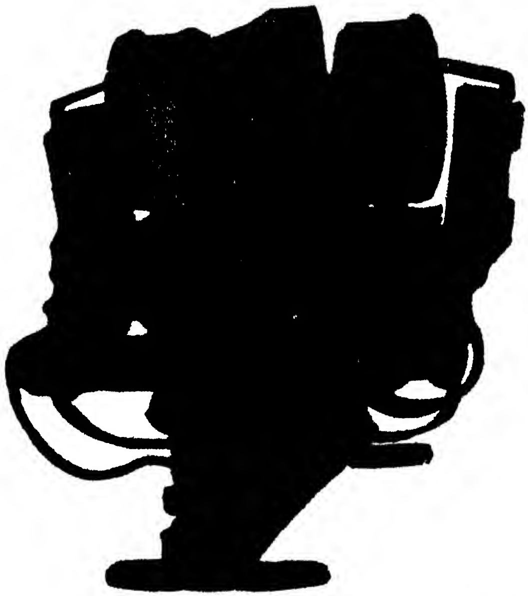


FIG. 4,286.—Relay switch. *Its use* is for handling the motor current inasmuch as this current is too great to be handled by the contact making volt meter. This is a double pole, double throw switch electrically operated by two *a.c.* magnets. *It consists essentially* of two double pole contactors mounted back to back and mechanically interlocked, forming a double pole double throw contactor type switch for reversing the regulator motor. The motor is caused to rotate in one direction or the other, depending on whether the voltage of the feeder is to be raised or lowered, as determined by the closing of the main contacts on the contact making volt meter which controls the excitation to the relay

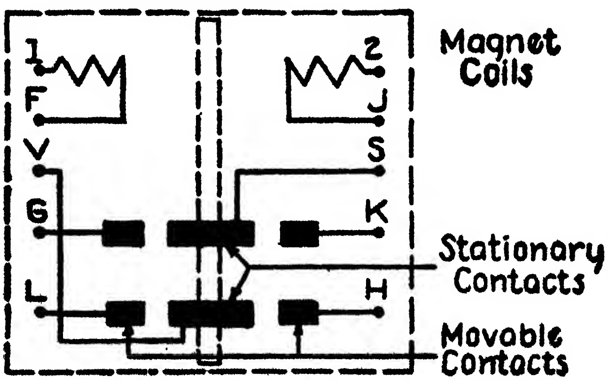


FIG. 4,287.—Wiring diagram of relay switch.

Auxiliaries for Induction Voltage Regulators.—Automatically operated regulators do not differ from the motor operated regulators in so far as the regulating itself is concerned, but it is necessary to provide a set of auxiliaries for accomplishing

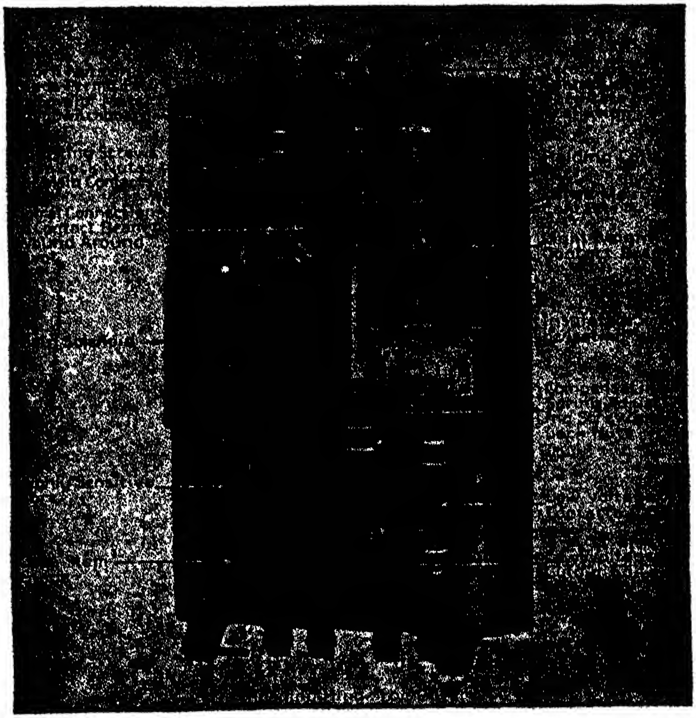
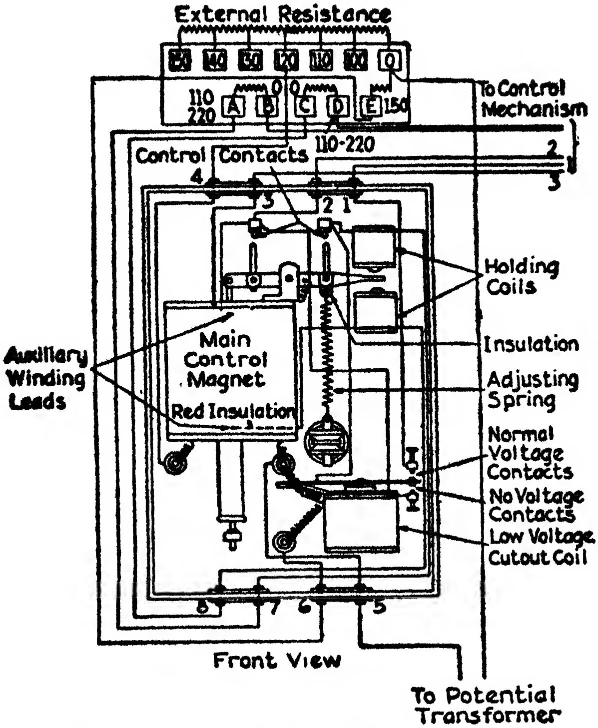


FIG. 4,288.—Contact making volt meter. *It consists of* a solenoid and a laminated iron core which is supported partly by a spring and partly by the current in the solenoid. This iron core is connected to one end of a lever which is pivoted at the center. Two contacts are mounted on the lever equi-distant from the pivot. When the core is raised or lowered, one of the two contacts will make contact with the corresponding stationary contact mounted directly over it, thereby closing the control circuit. One side of a low tension alternating control circuit is connected to the contacts on the lever, and the other side is brought through the energizing coils of the relay switch to the stationary contacts. When the line voltage is normal the lever is horizontal and its contacts are equi-distant from the stationary contacts. A variation in voltage either way from normal causes the lever to move, and if the change exceed the predetermined value for which the meter has been adjusted, one pair of contacts will close. This energizes one of the relay switch coils which in turn closes the motor circuit causing it to move the regulator armature in a boosting or lowering direction depending on the variation in the line, until the predetermined line voltage is again restored. The contact making volt meter is very sensitive and responds quickly to voltage changes. It is usually adjusted to operate the regulator whenever the line voltage varies 1% either

automatic operation. For the single phase regulator the auxiliaries consist of:



1. Relay switch.
2. Contact-making volt meter.
3. Potential transformer.
4. Current transformer.
5. Line drop compensator.
6. Position indicator.

FIG. 4,289.—Contact making volt meter connections.

FIG. 4,288.—*Text continued.*

way from normal. In order, however, to prevent unnecessary operation of not only the meter but also of the relay switch, motor, and regulator, caused by small intermittent voltage fluctuations which it would be undesirable to correct, the meter is provided with holding coils. These coils are connected in multiple with the relay switch coils and are energized simultaneously with them, their effect being cumulative with that of the pull of the solenoid whenever there is sufficient change in voltage to close the main contacts. This extra force is sufficient to keep the contacts closed until the motor has had time to start and change the setting of the regulator. Chattering of the contacts is thereby prevented and the life of the contacts is increased, particularly that of the relay switch contacts, since these contacts are not called upon to break the starting current of the motor. A low voltage cutout is also mounted on the meter so that if for any reason the feeder circuit should be opened the regulator will rotate to the maximum lowering position instead of the maximum boosting position as would be the usual tendency. In this way the possibility is avoided of impressing a higher voltage on the feeder than desired when it is again placed in service. The low voltage cutout, however, can be adjusted so that the regulator will remain in the same position which it is occupying at the time the feeder is opened if this be desired.

For three phase regulators the same auxiliaries are provided, with the exception that two current transformers are included instead of one as for the single phase regulator. Diagrams of the connections for single phase and three phase automatically operated regulators are shown in figs. 4,284 and 4,285.

In order that the actual voltage at a distant point on a distribution system may be read at the station some provision must be made to *compensate* for the line drop, that is to say, for the difference in voltage between the alternator and the center of distribution.

In order to do this a device which is known as a "line drop compensator" is placed in the volt meter circuit as shown in the diagram, fig. 4,291.

A line drop compensator consists of a variable resistance and reactance (each independently adjustable) by means of which, when used with an

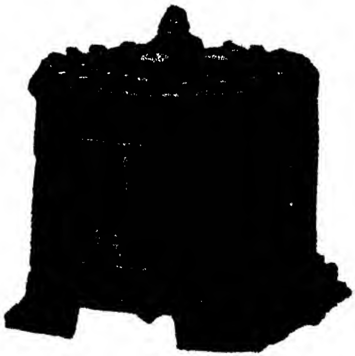


FIG. 4,290.—*Line drop compensator. Used to* reproduce in miniature the resistance and reactance drops to a predetermined point in the line. The function of the compensator is to lower the impressed voltage on the contact making volt meter used with an induction voltage regulator thereby causing the regulator to maintain normal voltage at this predetermined point. *It consists of* a resistance in series with a reactance, both being provided with taps brought out to dial switches, so that the amount of resistance and reactance in series with the current transformer can be varied independently. The dials are provided with 21 points, that is, 20 steps for both resistance and the reactance windings, each step being equivalent to 1 volt drop with 5 amperes flowing through the windings. The voltage drop is, of course, proportional to the current so that if instead of 5 amperes it were 2.5 amperes the voltage drop per step would be ½ volt.

NOTE.—*The potential transformer* for energizing the control coil of the contact making volt meter used with induction regulators, should have such a ratio as to give 110 volts on the secondary with the primary connected across the line and the regulator in the neutral position.

NOTE.—Standard instrument *current transformers* are used when it is desired to compensate for line drop. It is permissible to use the current transformers for the operation of indicating ammeters in addition to the regulator, but it is not recommended that they be used with the various types of watt meters as the volt ampere load would introduce errors in the reading of such instruments.

automatically controlled induction regulator, or with an alternator voltage regulator, correct line drop compensation can be obtained at some predetermined point on the feeder regulated regardless of the load or the power factor of the load on the feeder, provided, however, that the load is taken from the feeder at or beyond the point at which constant voltage is to be maintained.

Polyphase Induction Regulators.—In the polyphase regulator, the excitation is produced by the combined action of shunt windings connected across the separate phases of the

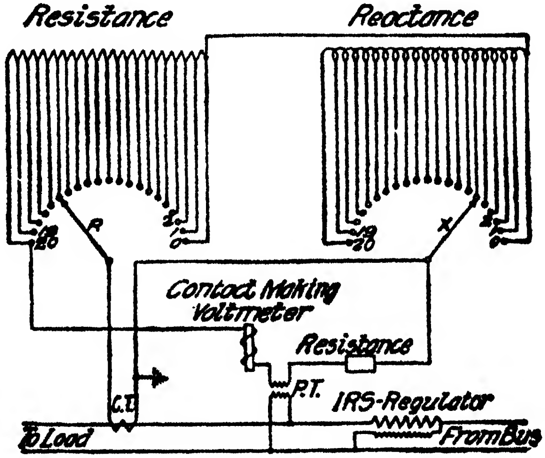
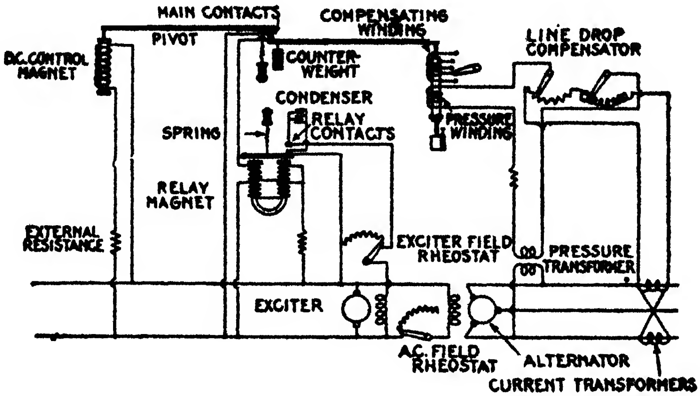


FIG. 4,291.—Connections of line drop compensator when used with induction voltage regulator. Induction regulators are usually employed to compensate for line drop in the feeder and to maintain normal voltage at some predetermined point of the feeder distant from the station. To accomplish this, the line drop compensator is used to reproduce in miniature the resistance and reactance drops to the predetermined point designated as the center of distribution. This is done by adjusting the ohmic and the reactive voltage drops across the compensator by means of the dial switches so that they will correspond to the ohmic and reactive drops in the feeder to some predetermined point, so that the voltage impressed on the contact making voltmeter will correspond to the feeder voltage at this point. The regulator, therefore, will be caused to raise or lower the voltage in the station in accordance with variations on the line and provide a means for holding the voltage at the point on the feeder distant from the station for all conditions of voltage, load, and power factor within the limits of the capacity of the regulating equipment.

NOTE.—*It is desirable,* in any system of distribution, to read the active voltage at the point of distribution, by means of the volt meters in the station. A conpensator proper consists of a variable resistance and a variable inductance, and sometimes a current transformer. In wiring, the volt meter, instead of being connected directly across the secondaries of a pressure transformer, has inserted in series with it, portions of the resistance and inductance of the compensator. These are so connected that the drop in pressure across them will be combined with that of the pressure transformer, so that the volt meter reading indicates the pressure at the center of distribution or end of the line.

system. The magnetizing flux produced has a practically constant value, but does not have a constant direction. The magnetic field is a rotating one, not an alternating one, as in the single phase type. All of the slots on the



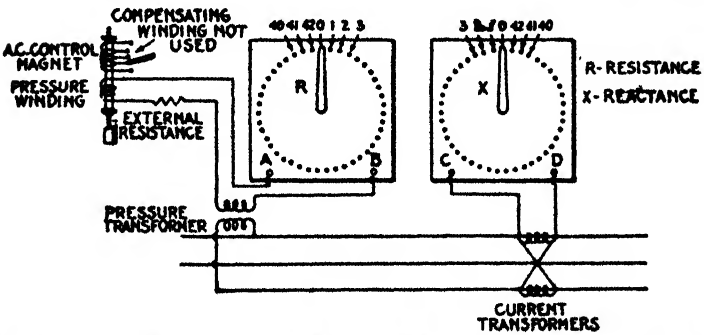
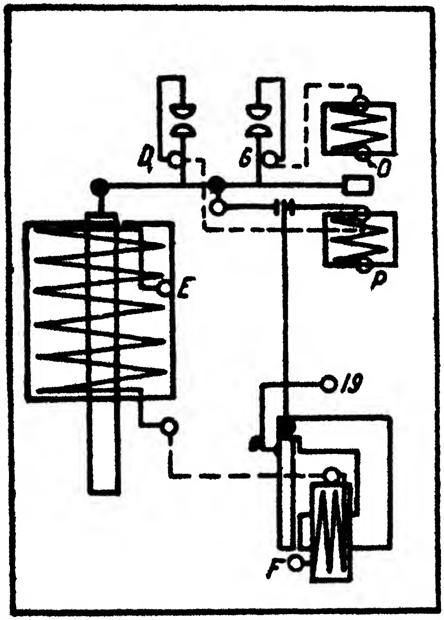


FIG. 4,292 and 4,293.—Diagram of *automatic voltage regulator*, using *line drop compensator*. For ordinary installations the compensating winding on the alternating current control magnet is connected to a current transformer in the main feeder. A dial switch is provided by which the strength of the alternating current control magnet can be varied and the regulator made to compensate for any desired line drop up to 15 per cent., according to the line requirements. Where the power factor of the load has a wide range of variation, a special line drop compensator, such as shown in fig. 4,293, adapted to the regulator would be desirable. The connections are readily understood by the diagram. The number of condenser sections which will prevent undue arcing at the relay contacts depends on the characteristics of the exciter. They may be roughly estimated by allowing one section for each 15 *kw*. capacity for exciters with laminated poles, and one for each 22 *kw*. capacity for exciters with solid steel poles. It is necessary though to have one condenser section for each pair of relay contacts, and at times it becomes necessary to apply a double section for each pair of contacts. In the lower figure the line drop compensator and connections are reproduced in more detail on a larger scale.

of a polyphase regulator armature are filled with the windings of the various phases symmetrically arranged, and the secondary or series winding is similarly arranged on the inside circumference of the stationary core.



The voltage induced in the secondary is due to the rotation of the flux produced by the combined action of the primaries. The voltages generated in the series windings of the various phases, are, therefore, of the same value and are constant for all positions of the armature.

FIG. 4294—Diagram of Westinghouse automatically controlled primary relay; front view. This relay is connected through the compensator to the voltage transformer and is sensitive to voltage changes of the outgoing feeder. Under normal conditions the moving arm in the primary relay is horizontal. With a change in voltage the plunger in the relay coil moves up or down and closes either the left hand or right hand set of contacts thereby causing the electrically operated secondary relay to close its contacts and start the operating motor in such direction as to lower or raise the voltage on the feeder as may be required to correct the change and bring the voltage back to normal.

The variation in the line voltage produced by the regulator is due to a phase displacement as shown graphically in fig. 4,295.

Because of the rotation of a similar field produced by the current in the series coils, the currents in the shunt windings are constant, regardless of the position of the armature, for a given line current, and the currents in the shunt windings are taken from the line or delivered back into the system as the armature is rotated from maximum boost to maximum lower in the phase relation as represented by the secondary voltage

generated. This condition is due to the fact that the current in the series winding (the line current) determines the direction of the voltage in the series or secondary winding.

With the arrangement of the shunt windings necessary in the polyphase regulator, the impedance of the apparatus is comparatively small without the use of the short circuited coil required in the single phase machine, and the total ampere turns of the primary are always equal to the total ampere turns of the secondary. This accounts for the currents in the shunt winding being out of phase with those in the series coils in any other than the maximum boost or lower positions.

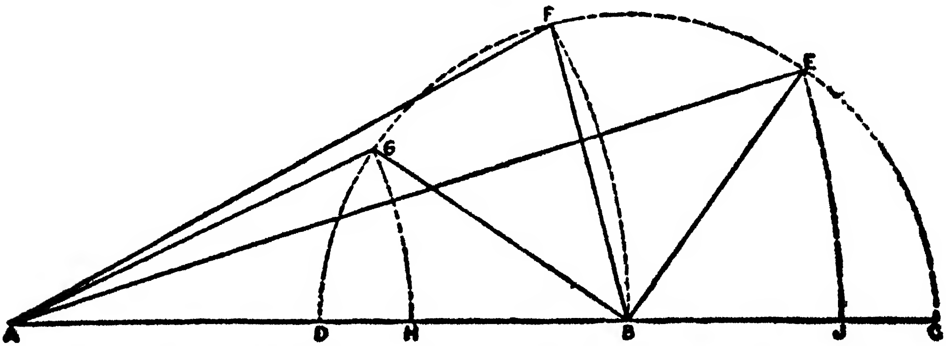


FIG. 4,295.—Diagram illustrating operation of polyphase induction regulator. *In operation,* when the regulator is in the position of maximum boost, the line AB, in the figure represents the normal bus bar voltage, BC, the regulator voltage, and AC, the resultant feeder voltage. When the regulator voltage is displaced 180 degrees from this position, the regulator is in the position to deliver minimum voltage to the feeder, the regulator voltage being then represented by BD, and the resultant feeder voltage by AD. When the regulator voltage is displaced angularly in the direction BF, so that the resultant feeder voltage AF, becomes equal to the normal bus bar voltage AB, the regulator is in the neutral position. Intermediate resultant voltages for compensating the voltage variations in the feeders may be obtained by rotating the moving element or primary in either direction from the neutral position. *For example,* by rotating the primary through the angle FBE, the resultant voltage may be made equal to AE, or AJ, thereby increasing the feeder voltage by an amount BJ; or by rotating it in the opposite direction through the angle FBG, the feeder voltage may be reduced by an amount BH.

Ques. How is the control apparatus arranged?

Ans. Two relays are employed with each regulator, a primary relay connected to the feeder circuit and operating under changes of voltage therein, and a secondary relay connected between the primary relay and the motor, and operated by the contacts of the former, for starting, stopping and reversing the

motor in accordance with changes in the feeder voltage, thereby causing the regulator to maintain that voltage at its predetermined normal value.

Two relays are used because a primary relay, of sufficient accuracy and freedom from errors due to temperature and frequency variations, could not be made sufficiently powerful to carry the relatively large current required for operating the motor.

Ques. What names are given to the relays?

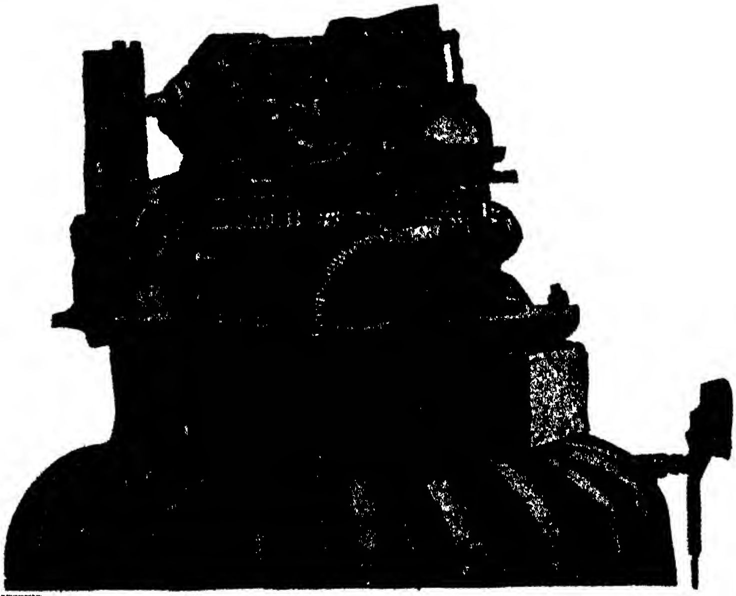


FIG. 4,296.—General Electric three phase induction voltage regulator. Close front view showing operating mechanism.

Ans. The primary or contact making volt meter, and the secondary or relay switch.

Ques. Why does the movable contact arm of the primary relay tend to remain nearer one of the stationary contact points than the other?

Ans. This is due to the tendency of the relay to open the

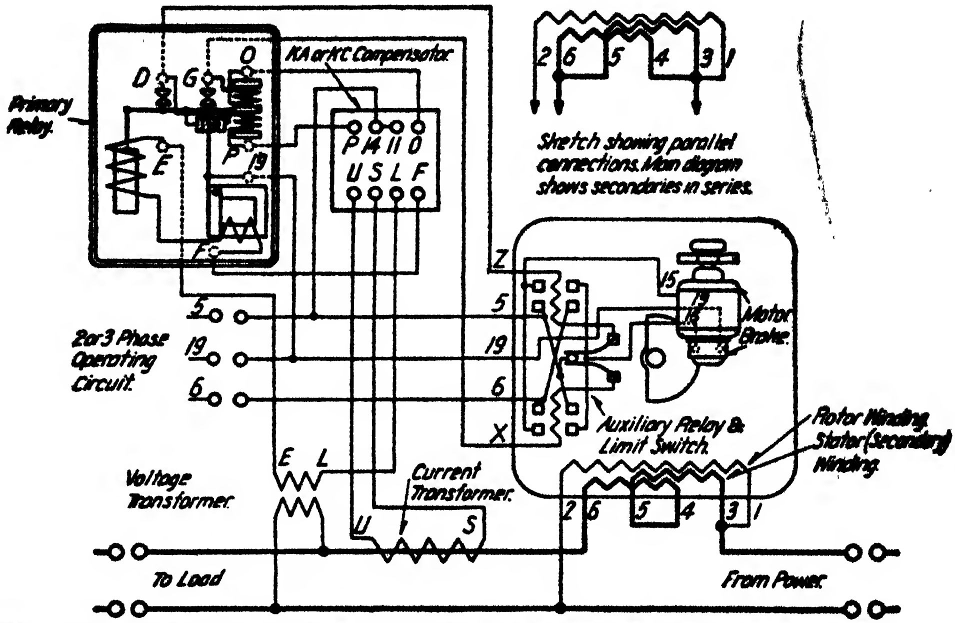


FIG. 4,297.—Westinghouse diagram of connections for automatic single phase regulator.

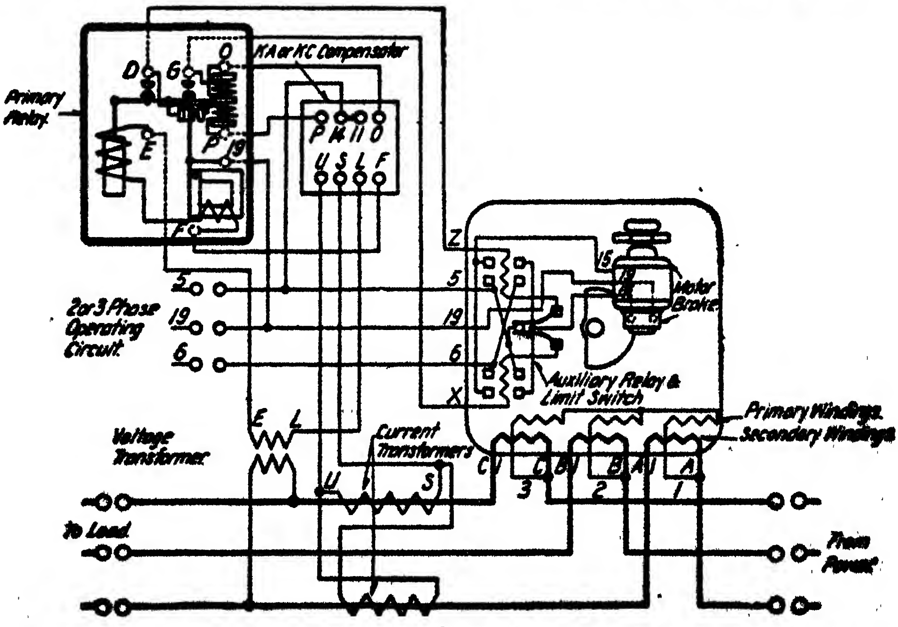


FIG. 4,298.—Westinghouse diagram of connections for automatic three phase regulator

contact whenever the voltage equals that at which the contact closes.

Ques. What provision is made in the primary relay to prevent vibration or chattering?

Ans. Two auxiliary windings are provided: one in series

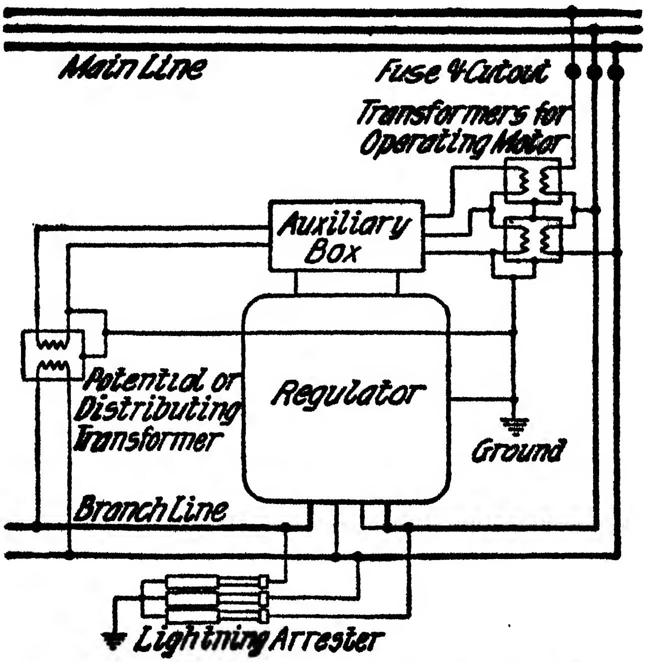
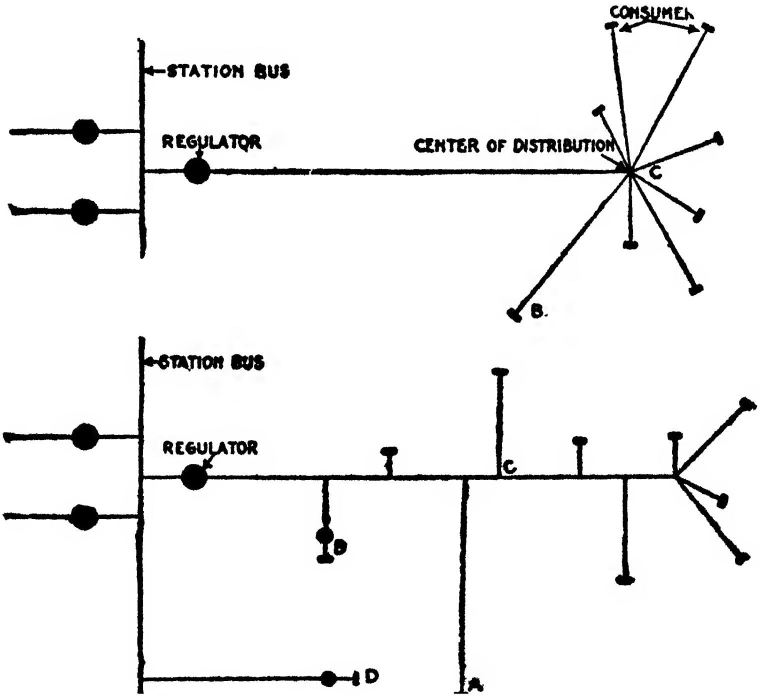


FIG. 4,299.—General Electric connection diagram for outdoor automatic induction voltage regulators, showing protective devices.

with each of the stationary contact points and so arranged as to assist in making the contact by increasing the pressure on the contact points at the instant of closure.

The best effect of the compounding action of the auxiliary coils is obtainable when arranged for ¾ per cent. of the torque of the main coil.

Outdoor Induction Voltage Regulators.—In some generating stations *the voltage is maintained constant at the bus bars and the line drop compensated by automatically operated regulators connected in the main feeders*. It is possible in this way to obtain constant voltage at all loads at the various distribution centers, that is, at those points on the feeders where the lines of the majority of consumers are connected as shown in fig. 4,300.



FIGS. 4,300 and 4,301.—Systems of distribution illustrating use of outdoor induction voltage regulators.

It is evident, however, that, while the voltage at the center of distribution can be maintained constant, no account can be taken of the drop in the lines between this center and the consumers. This drop is generally negligible, except in some particularly long lines, as, for example, consumer B, in fig. 4,300.

In order to obtain perfect regulation at B, it would be necessary to install a separate regulator in that line, this regulator to be installed either at the center C, or preferably at B.

In a great many cases the power distribution is not as ideal as indicated in fig. 4,300, but rather as shown in fig. 4,301, that is, the consumers are connected all along the feeder. In this case there is no definite center of distribution, and the automatic regulator installed in the station can be adjusted to give only approximately constant voltage at an imaginary center of distribution C; that is, the voltage cannot be held constant at any definite point during changes of load distribution.

The majority of the consumers may, however, obtain sufficiently good voltage while a few may have reason for criticism. To overcome this difficulty it is necessary either to increase the copper in the feeder or else to install small automatic regulators.

There are also cases where a small amount of power is transmitted a long distance through a feeder direct from the station.

The outdoor type regulator is shown in fig. 4,302.

Load Ratio Control.—This system permits *changing the voltage ratio of a transformer without interrupting the load.* Load ratio control equipment can be applied to practically all

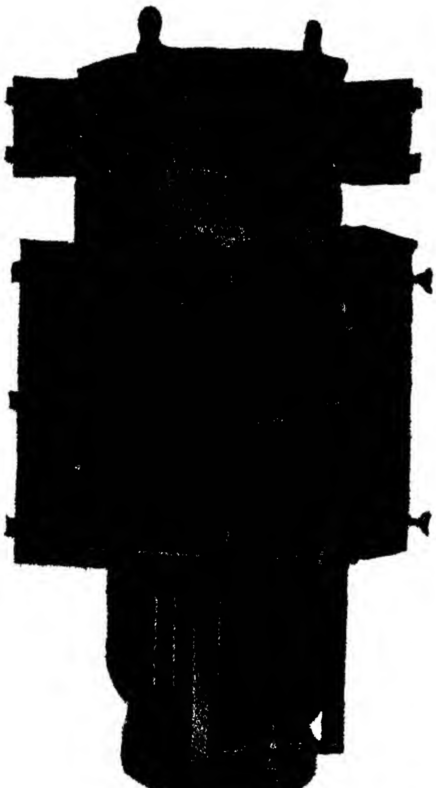


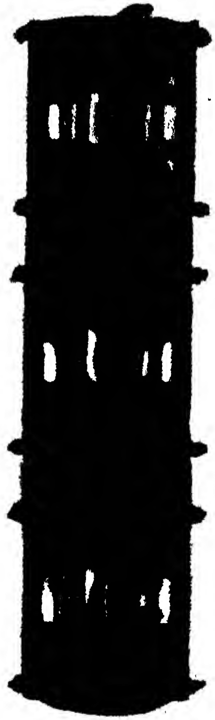
FIG. 4,302.—General Electric single phase automatic induction regulator arranged for outdoor installation.

regulation problems, above a point where it is not economical to use induction regulators. There is no definite upper limit to its application either of *kva.* voltage or current though in some cases it is necessary to use series transformers and sometimes exciting transformers to get within the voltage or current limitations of the apparatus.

This method of control involves *the use of two local circuits capable of carrying the load simultaneously*. This permits picking up the load on one ratio before it is dropped from another.

Obviously carrying a load simultaneously on two tap connections would involve a destructive short circuit between those taps unless a suitable impedance was introduced to limit the exchange current.

All types of load ratio control include such an impedance, usually consisting of leakage

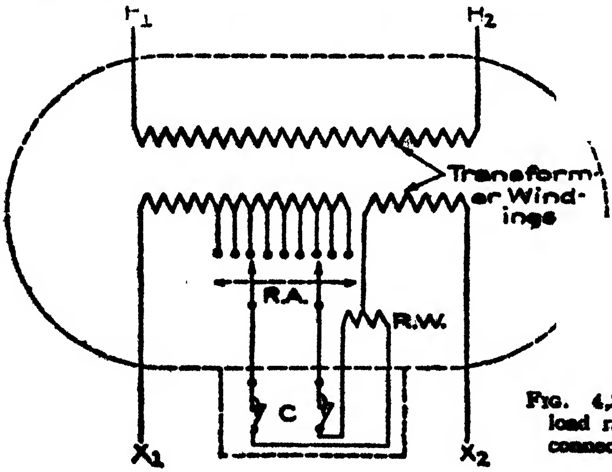


FIGS. 4,303 and 4,304.—General Electric single phase and three phase ratio adjusters for load ratio control regulator. They operate by means of an eccentric so that with a light torque on the shaft, a heavy pressure is placed on the contacts as they "wipe" into position. The cylindrical contact bars, to which tne tap leads are bolted, are insulated from each other by Herkolite tubes inserted in molded compound heads.

reactance between special windings on the transformer core or of a separate iron core reactor.

Earlier tap changing devices utilized the preventive reactor to obtain additional ratios between taps by operating continuously on two taps with the reactor bridging them.

Later development of load ratio control equipment advanced the scheme of operation so that an actual tap could be used for each ratio and the preventive reactor short circuited except during a ratio change. The reactor is only one half the size required by the previous method and is in series or parallel with the load only for the two or three seconds required for the operation of the mechanism. The ratio steps are always uniform regardless of the load and the no load loss is a minimum and the same on all ratios.



Figs. 4,305 and 4,306, show typical applications of the modern method to delta and Y connected transformers.

FIG. 4,305.—General Electric load ratio control in a delta connected transformer.

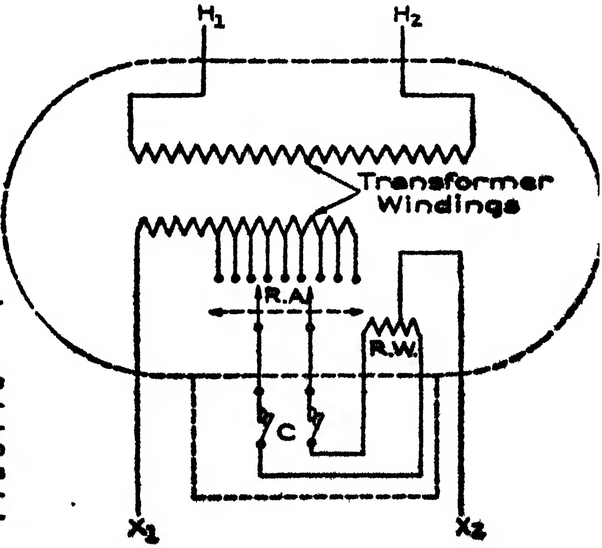
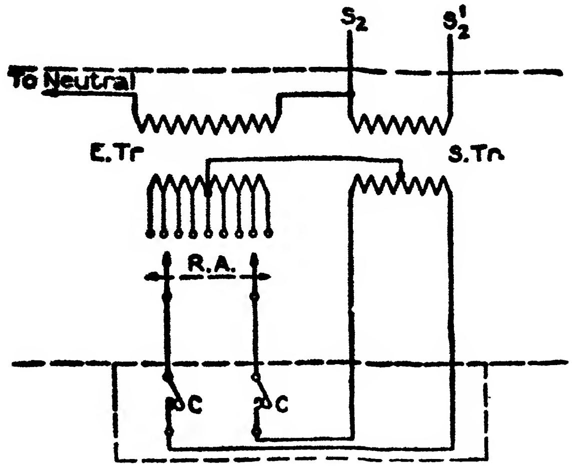


FIG. 4,306.—General Electric load ratio control in a Y connected transformer.

NOTE.—*Reference letters for above diagrams:* R.W., reactive windings; E. Tr., excitation transformer; T.A., tap auto-transformer; S. Tr., series transformer; R.A., ratio adjusters; C., contactors; E., excitation leads; S., series leads.



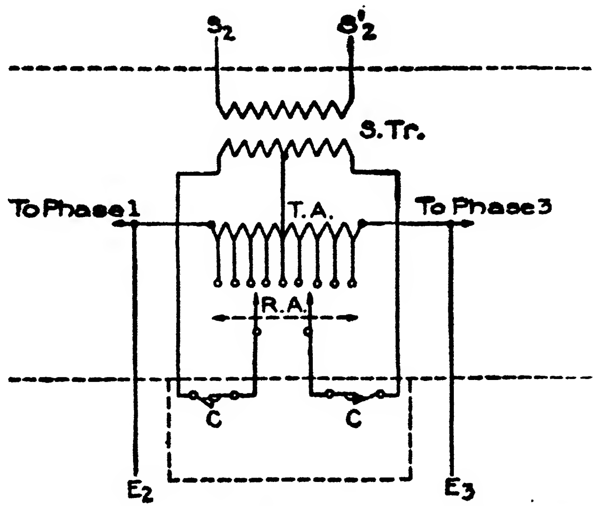


FIG. 4,307.—Middle phase of a three phase regulating transformer consisting of an excitation transformer with taps and a series transformer.

FIG. 4,308.—Middle phase of a three phase regulating transformer consisting of a tap auto-transformer and a series transformer.

The standard equipment consists of two ratio adjusters and an intermittent gear mounted inside the transformer tank and two cam operated oil immersed contactors and a driving mechanism mounted on the side of the tank. Both ratio adjusters are normally connected to a common tap. The operation in changing taps under load consists of turning first one and then the other ratio adjuster to a new position, the corresponding contactor being open during the movement of each adjuster. The taps are changed by the ratio adjusters inside the tank, and it is necessary to have only two contactors, one in series with each ratio adjuster. These contactors are outside the tank, whereas the ratio adjusters and intermittent gear mentioned previously are inside the tank and minimize the number of bushings through the tank wall as well as the voltages in the contactor box.

The driving mechanism consists of:

1. *D.c.* motor.
2. Brake.
3. Relay switch.
4. Limit switch.
5. Position indicator.

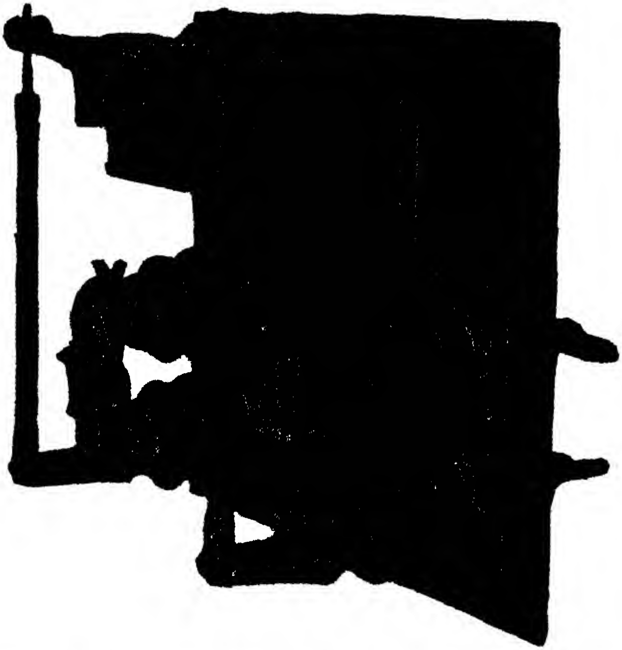


FIG. 4,309.—General Electric single phase contactor for load ratio control regulator. The two cam operated contactors are assembled as a unit on a heavy steel plate which is bolted with an oil tight joint to the side of the transformer tank, and are enclosed in an oil box provided with a suitable breather. The contactor elements are mounted directly on porcelain entrance bushings which project into the transformer tank. They are designed with current carrying contacts and with arcing tips to which deterioration from operation is confined.

6. Suitable gears for driving the main operating shaft and a drum controller mounted on that shaft.

The mechanism is controlled by means of a push pull switch mounted on the station switchboard. Once started the motor relay switch is sealed magnetically until a change of one step

in ratio is completed when it stops the motor. Automatic control is provided when necessary if the service require it.

To indicate the tap position of the transformer there is a dial indicator mounted on the mechanism and a dial switch which operates a lamp indicator furnished for mounting on the switchboard. The motor relay switch is standard equipment used for the control of machine tool motors.

The magnetic brake is mounted on the motor shaft and is connected in parallel with the motor field. The limit switch that stops the motor

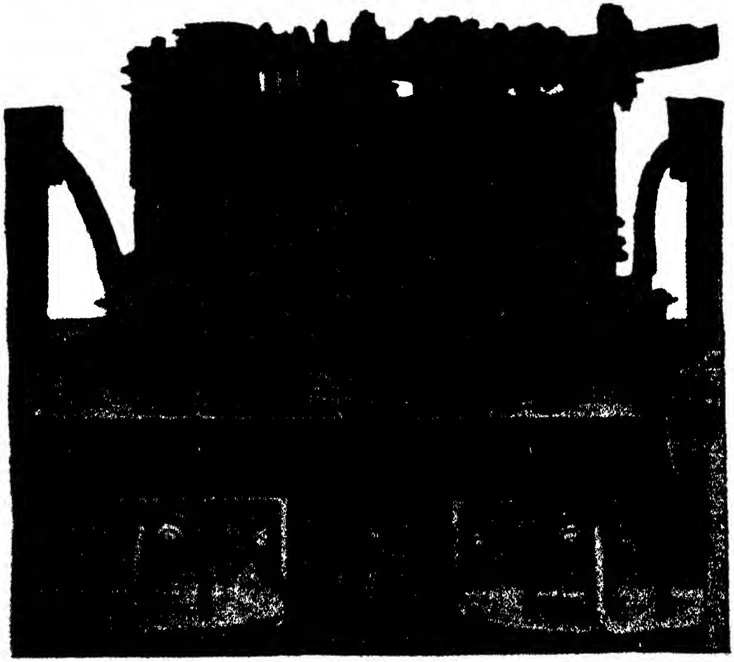


FIG. 4,310.—General Electric intermittent gear, universal coupling and ratio adjuster assembly for load ratio control regulator. The intermittent gear is designed to bring each ratio adjuster up to speed gradually before the teeth mesh, thus permitting the equipment to operate without mechanical shock. On any ratio, the intermittent gear locks the two ratio adjusters in their correct positions, and also locks each adjuster during the operation of the other. There is a suitable universal joint between the gearing and the tank wall.

when the mechanism has reached either limiting tap position is similar to the equipment used on induction regulators. Provision is made for emergency manual operation.

There is a clutch to release the motor and a spring buffered mechanical stop at each limiting position.

Auxiliary contacts are provided on the dial switch and energize a red light on the switchboard indicator during the operation of the mechanism. A delay relay is connected in parallel with the red light for use with a noise alarm. Thus, in addition to the red light giving a visual warning there is also an audible warning which is brought into play by the action of the delay relay should the operating mechanism fail to complete the tap change and leave the preventive reactor in the circuit. This visual and audible warning advises the station operator that the mechanism has not completed its cycle and permits it to be completed manually.

If for any reason the station operator be not available to complete the operating cycle manually, no harm would be done since the preventive reactor is designed to carry full load current continuously.

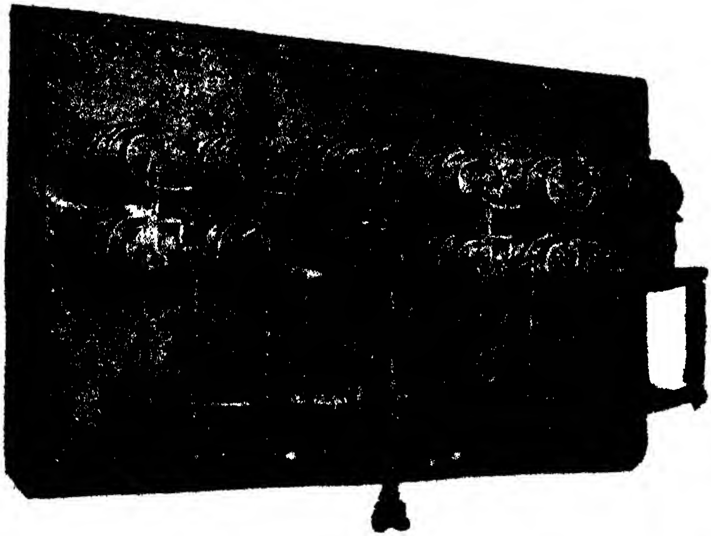
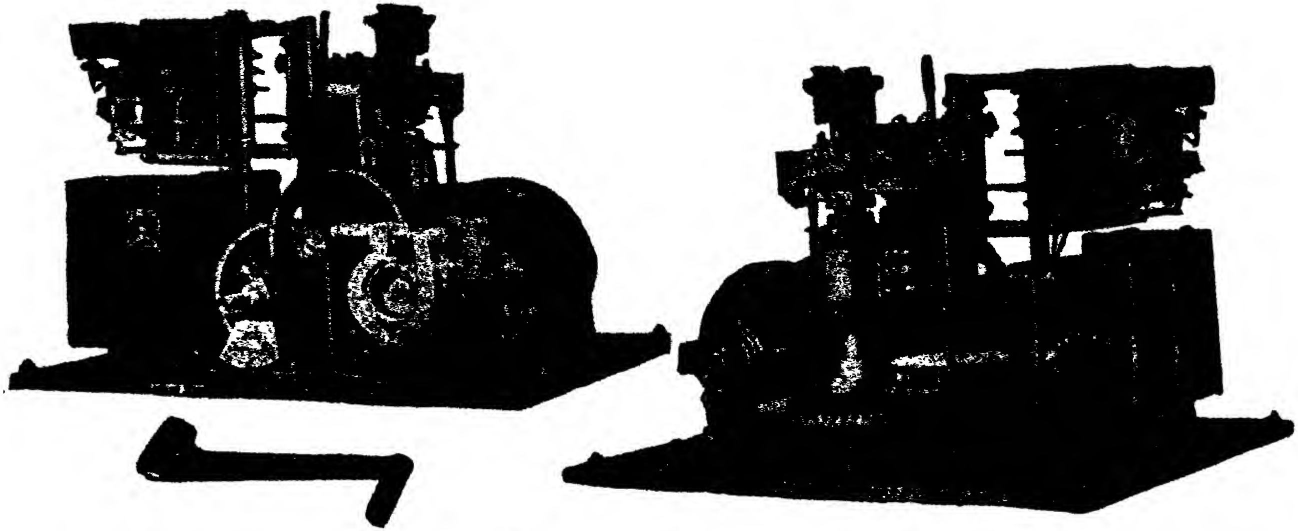


FIG. 4,311.—General Electric three phase contactor for load ratio control regulator.

Voltage Regulation of Alternators.—The necessity for voltage regulation of alternators was recognized coincidentally with the operation of the first Edison bipolar dynamos. The loads, however, were relatively small and feeder net works were not required, so that voltage regulation was usually obtained by manually operating the dynamo field rheostats and



FIGS. 4,312 to 4,314.—Front and rear views of General Electric operating mechanism for load ratio control regulator. The driving mechanism consists essentially of a *d.c.* motor, brake, relay switch, limit switch, suitable gears for driving the main operating shaft, drum controller mounted on that shaft, visual position indicator, and dial switch for remote indication. The mechanism is controlled by means of a push pull switch furnished for mounting on the station switchboard. Once started, the motor relay switch is sealed magnetically until a change of one step in ratio is completed. This operation requires but from two to three seconds. The motor relay switch is standard equipment used for the control of machine tool motors. The magnetic brake operates on the motor shaft and, being connected in parallel with the motor field, insures stopping on exact positions. The limit switch which stops the motor when the mechanism has reached either limiting tap position is standard equipment used on induction voltage regulators. The mechanism is completely wired through cutouts and fuses to terminal boards. A conveniently located metal conduit entrance is provided for the control circuits. To indicate the position of the ratio adjusters there is a dial indicator on the mechanism and a dial switch which operates a lamp indicator (shown in fig. 4,315) furnished for mounting on the switchboard. Auxiliary contacts on the dial switch energize a red light on the switchboard indicator during the operation of the mechanism. A delay relay is furnished for use in parallel with the red light to operate an alarm in case the operation is delayed beyond the normal time. Arrangement is made for manual operation, the handle (fig. 4,313) being so connected that a change of ratio can be made by four revolutions. There is a clutch to disengage the motor during hand operation; also a spring-buffered mechanical stop at each limiting position.

the control was further simplified by the practice of supplying each feeder with a separate dynamo. To meet the increasing demand for energy, the size of dynamo and the length and number of feeders had to be so greatly increased that improvements in the methods of controlling the voltage became imperative.

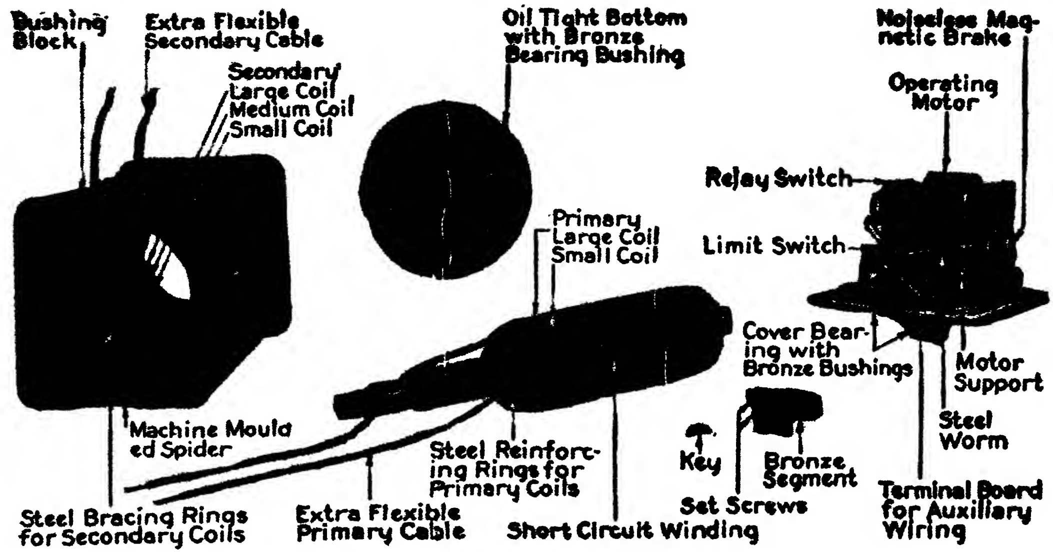
Furthermore, as the loads became more diversified, elimination of the personal element in the control of voltage was made necessary. Automatic solenoid operated rheostats, as well as other devices based on this principle, were developed to meet this demand, but the problem was not solved until the automatic voltage regulator was introduced.

FIG. 4,315.—Lamp indicator for General Electric load ratio control regulator.

The alternating voltage is regulated indirectly by opening and closing rapidly a shunt circuit across the exciter rheostat, thus varying the exciter voltage in order to maintain the desired alternating voltage. In order that the simplicity of this regulator may be understood, it should be borne in mind that the regulator consists mainly of two parts, a *d.c.* control system, and an *a.c.* control system.

The former is simply a *d.c.* regulator having a main control magnet and relay magnet connected across the exciter mains, the contact of the relay being arranged to shunt the exciter field rheostat. This operation maintains not a constant but a varying exciter voltage, the value varying in accordance with the demands of the *a.c.* control magnet which is connected to the alternating bus, the latter magnet being considered as the *a.c.* portion of the regulator. It will be evident from the description under the illustration that the exciter voltage is controlled by the rapid opening and closing of the relay contacts.

The value of the voltage depends upon the position of the *a.c.* magnet core and lever arm, which in turn is dependent upon the value of the alternating voltage being held. At any constant load, speed and power



FIGS. 4,316 to 4,321.—General Electric 2,300 volt single phase induction regulator disassembled.

factor, the *a.c.* magnet core does not actually move, the regulator acting as a *d.c.* regulator maintaining the proper exciter voltage to give the correct *a.c.* voltage.

Should the power factor change or should a heavy load be thrown upon the alternator, the previous exciter voltage will then not give the correct *a.c.* voltage, therefore the *a.c.* core will drop slightly. This forces the lower main contacts against the upper main contacts which in turn closes the relay contacts. This, as previously explained, causes the exciter voltage to increase. The travel of the *a.c.* magnet core will continue until the exciter voltage has reached a value corresponding to that required to give normal *a.c.* voltage under the new conditions. The *d.c.* side of the regulator will then operate and maintain the exciter voltage of the regulator at this high value in order to hold again the proper *a.c.* voltage.

In case the load drop on the *a.c.* alternator, the reverse action takes place and the regulator maintains a lower exciter voltage, in order to give the correct *a.c.* voltage.

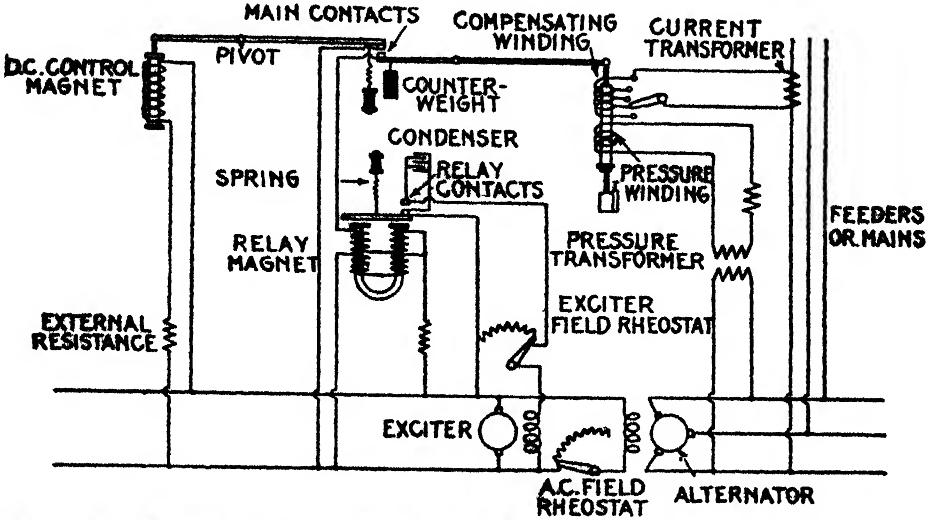


FIG. 4,322.—Elementary connections of General Electric automatic alternator voltage regulator. The diagram shows the *d.c.* control magnet connected across the exciter bus and provided with two cores, the lower being a fixed stop core, the upper a movable core attached to a pivoted lever at the opposite end of which is mounted a flexible contact. The pull of the magnet is shown opposed by one spring, but in practice there are actually four springs in multiple that pick up at different exciter voltages. A differentially wound relay magnet is also shown connected to the exciter bus, one winding being permanently connected to the bus, while the other is arranged to be opened and closed by the floating main contacts. The relay has pivoted armatures to which there is a spring attached to oppose the pull of the magnet. The contacts are connected across the exciter field rheostats. Condensers are connected across the contact points to prevent destructive arcing. The voltage winding of the *a.c.* control magnet is shown connected across the generator bus through a voltage transformer, while the opposing or compensating winding is shown connected to a current transformer in the feeder circuit. This magnet is of the ordinary solenoid type, having a laminated iron core which is attracted upward by the magnetizing force. The core is attached to a pivoted level, at the opposite end of which a counterweight is supported to assist in bringing the lever and core to a point of equilibrium, and on the same end of this lever is shown the lower main contact which, in combination with the upper main contact, produces what are known as the floating main contacts.

NOTE.—*Practically all the methods* employed for regulating the voltage of dynamos and circuits, are applicable to alternators and alternating current circuits. *For example:* in order that they shall automatically maintain a constant or rising voltage with increase of load, alternators are provided with composite winding similar to the compound winding of dynamos, but since the alternating current cannot be used directly for exciting the field magnets, an accessory apparatus is required to rectify it or change it into direct current before it is used for that purpose. It is a fact, however, that composite wound alternators do not regulate properly for inductive as well as non-inductive loads.

When two or more exciters are required to furnish excitation to alternators, they may be connected in parallel or they may be controlled individually by standard regulators. Parallel operation of exciters provides for nearer uniform control and prevents losses in the alternators, due to circulating currents. When conditions are such as to make it impractical, to parallel the exciters, standard regulators may be used without change, and close voltage regulation will be obtained.

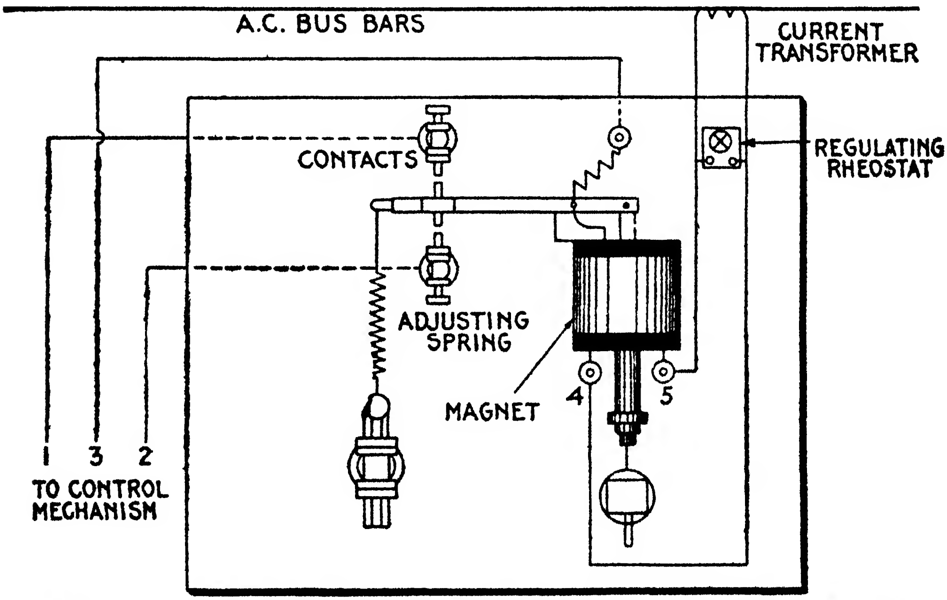


FIG. 4,323.—Diagram of connections of General Electric *contact making ammeter* for operating on alternating current circuits. *The instrument is designed to indicate* with the aid of a current transformer, *certain values of current in an alternating current system.* This value depends upon the setting of the regulating rheostat in parallel with the pressure coil of the ammeter. It is also possible with this instrument, together with the necessary control apparatus, to *hold* certain values of current. *By using a different magnet coil* this meter may be connected to a shunt instead of a current transformer and used on a direct current system.

If the exciters be operated in parallel they may be of different capacities and design, or driven by various sources of power, and the circulating currents resulting from variations in speed or design will merely affect the exciters, slightly lowering their efficiency. On the other hand, if they be not connected in parallel, the disturbances will be carried through to the alternators and the efficiency of the system will be affected more seriously. When a single regulator is used, frequent hand adjustment of the

exciter field rheostats may be necessary in order to reduce the circulating current to the minimum.

Furthermore, the regulator will have to be provided with at least one relay for each exciter, although the exciter capacities may be such that one relay would be sufficient for the control of the exciters if they were connected in parallel. The disadvantages of this arrangement can be overcome very readily by installing a regulator for each exciter and operating the regulators in parallel. Not only can the circulating currents between the alternators be eliminated, but greater flexibility of control and higher operating efficiency will be attained.

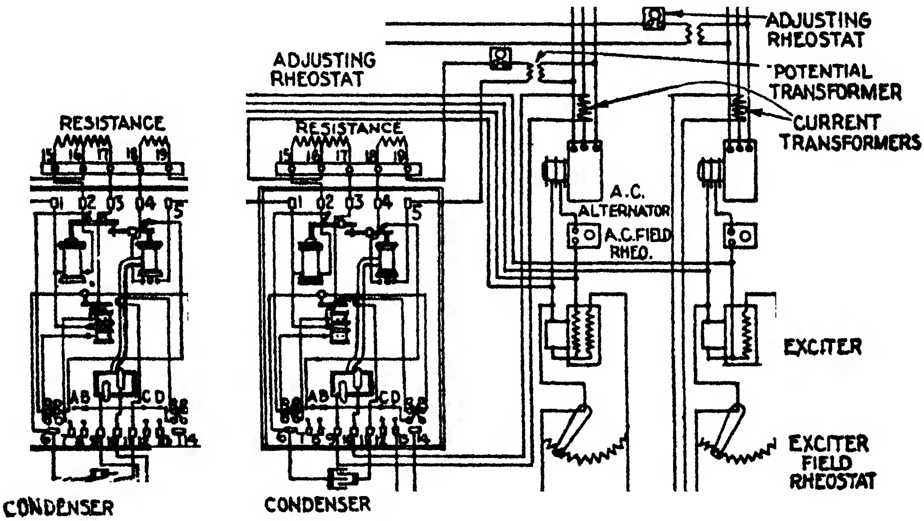


FIG. 4,324.—General Electric connection diagram for two alternator voltage regulators operating in parallel. The *a.c.* magnet has a voltage winding and a compensating winding. The compensating winding is connected to a current transformer in the line opposite to the two lines to which the voltage transformer is connected. When the power factor is unity and the load current is properly balanced between the different machines, the field produced by the current coil is 90° out of phase with the field produced by the voltage coil, and has an extremely slight effect. Should the power factor tend to shift from one alternator to the other, the regulator will be at once affected and will raise or lower the alternator excitation as required to eliminats the circulating current, since the latter is 90° out of phase with the load current, and therefore in phase with but directly opposed to the field of the voltage coil, thereby changing the pull of the voltage winding until balanced conditions have been restored. It should be noted that "out of phase" current transformers will be required for all of the regulators operating in parallel. Should it be necessary to compensate for line drop, additional current transformers and line drop compensators are required.

Parallel Operation of Alternator Voltage Regulators.—This method has become quite popular in a great many installations where it is desired to operate alternators with direct connected exciters and use a separate regulator for each equipment, permitting the control of each set as an individual unit. In considering the application of such a system of regulation to a number of alternators in a station, it should be

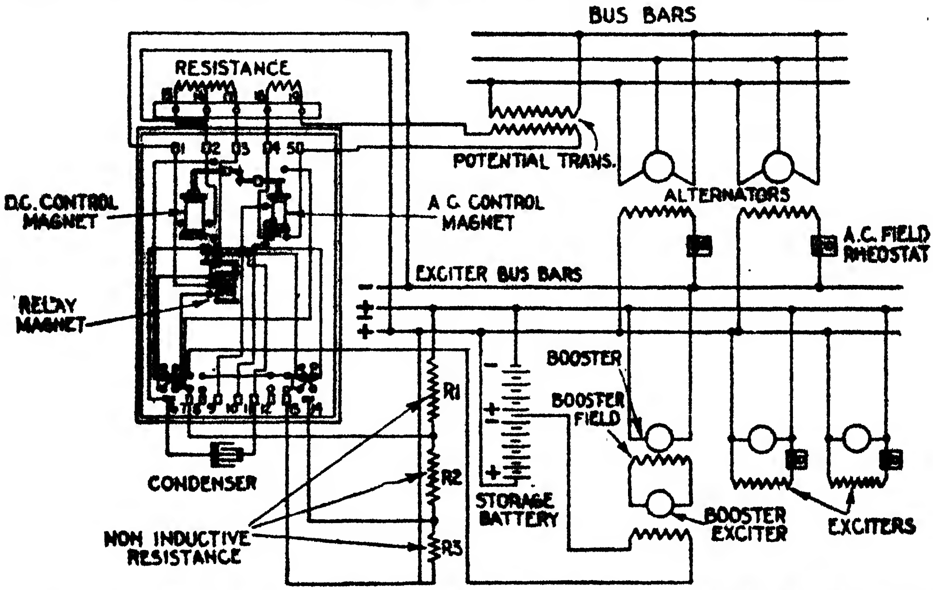


FIG. 4,325.—General Electric connection diagram of regulator with one arrangement of two exciters in parallel in conjunction with storage battery and booster. The regulator contacts are connected across the resistance R3, which is considerably greater than resistance R1 The R1, resistance is also greater than that of R2. *For example,* should R3, be short circuited by the regulator, the resistance R1, being greater than R2, causes the current to flow in the direction to boost the voltage. Should the contacts remain open, resistance R3, is inserted; the sum of R3 and R2, is greater than R1, and the current in the booster field flows in the reverse direction, causing the booster to buck the exciter voltage. This cycle of operation is repeated very rapidly, thereby maintaining a constant voltage on the *a.c.* bus. The booster for this system must have a current capacity equal to the combined currents required by the main alternator fields, and can be furnished for almost any range of boost or buck which may be demanded. This system is particularly adapted to large steam plants where a storage battery is used as an emergency device to take care of the excitation should anything happen to the exciters. It will be noted that no current transformer or line drop compensator is shown in the diagram, but compensation for line drop may be accomplished with this system of regulation in the same manner as with any standard voltage regulator by placing a current transformer or a line drop compensator in the main lighting feeder.

remembered that the change in excitation of any one of the alternators does not affect the bus voltage appreciably. The chief effect is to change the current supplied by that machine.

Increasing the excitation will make it take more current and decreasing the excitation will make it take less current.

To raise the station bus voltage it is necessary to increase the excitation for all machines. Division of load between the alternators depends on

FIG. 4,326.—General Electric regulator for alternators having exciters of small capacities. When two alternators operate in parallel and the exciters are also in parallel, one regulator may be used for the control of both exciters, provided the sum of the two field currents of the two exciters does not exceed the limit for which the relay is designed. The exciters may be either shunt or compound wound.

the power supply to each alternator and is entirely independent of the excitation. Successful operation of regulators in parallel, therefore, depends primarily on the control of the circulating current that may flow between two or more alternators or the proper division of the reactive currents in the system as a result of momentary differences in excitation. The method followed for eliminating such circulating currents is shown in fig. 4,325.

Variable Exciter Voltage System of Alternator Voltage Regulation.—This system is particularly adapted to plants where

it is necessary to run motors and other station auxiliaries from the exciter bus. With the standard type of voltage regulator, the regulation of the alternator voltage is accomplished by varying the exciter voltage and it is, therefore, impossible to run station auxiliaries from the exciter bus, but with this system the exciter bus voltage is not disturbed.

For example, the excitation on an *a.c.* system, assuming 125 volt excitation, usually required a range of from 50 to 125 volts but with this system the exciter bus can remain constant at 125 volts, a booster being

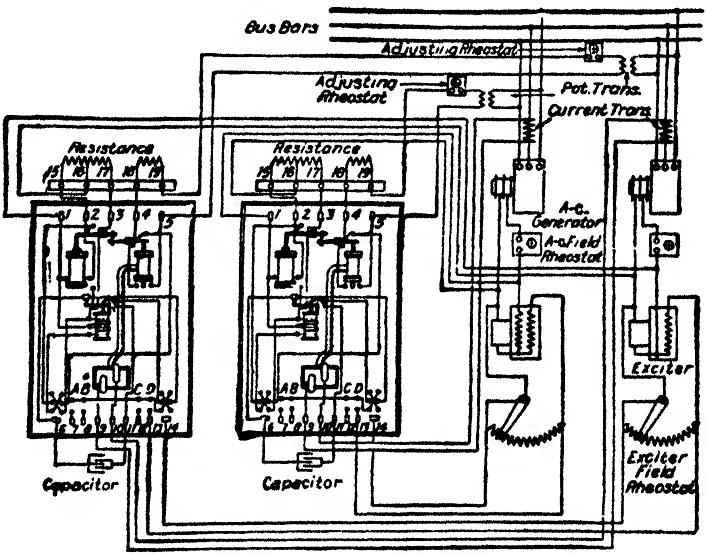


FIG. 4,327.—Diagram of connections for two General Electric automatic regulators operating in parallel.

inserted between the bus and the fields of the alternators which is capable of varying the excitation to maintain the desired alternator voltage.

The booster is separately excited by a small dynamo, which in turn has its field excited from the difference in voltage between a point on either a resistance connected across the exciter bus, or if a storage battery be used, the middle tap from the battery, and a point of variable voltage on a series of three resistances connected across the exciter bus, as shown in

fig. 4,325, so that the booster can be excited with either polarity, as required.

Voltage Regulation of Feeders.—The voltage of an alternator or number of alternators, as just explained, may be automatically maintained at normal for all conditions of load at the station bus or at any one center of distribution on the system, by means of an alternator voltage regulator.

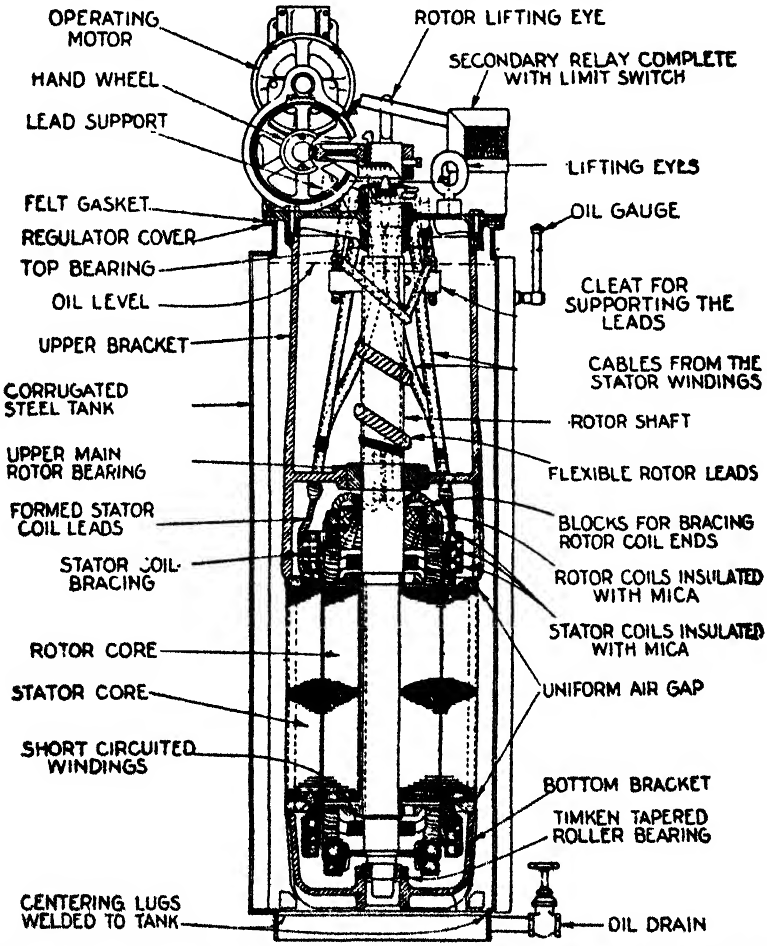


FIG. 4,328.—Westinghouse single phase induction voltage regulator, sectional view showing construction.

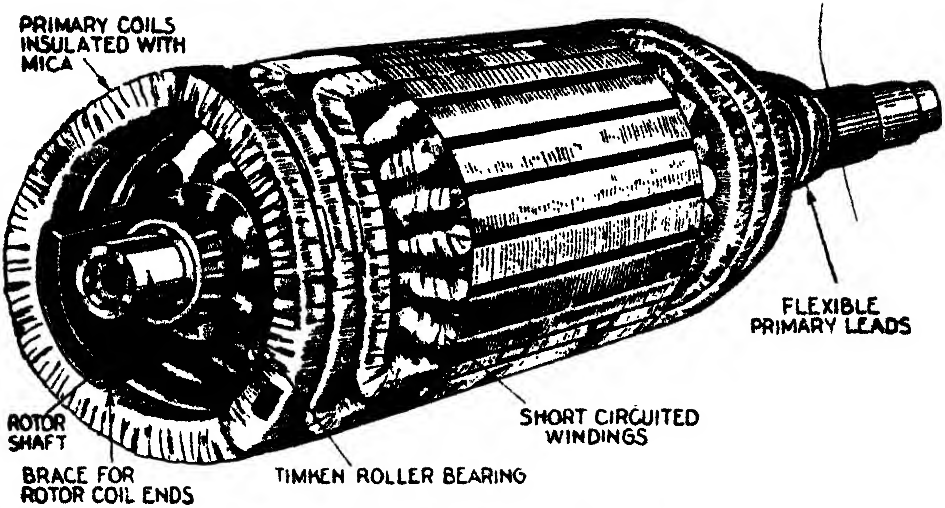


Fig. 4,329.—Westinghouse *rotor* for single phase induction voltage regulator.

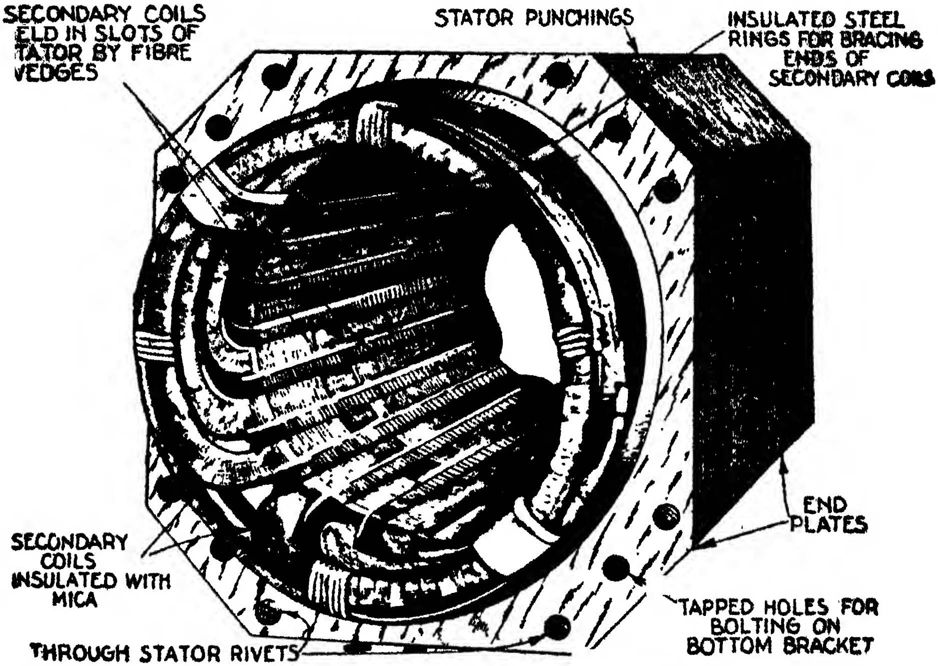


Fig. 4,330.—Westinghouse *stator* for single phase induction voltage regulator.

Where there are a number of feeders radiating from a station this method of regulation, however, will not be satisfactory unless all of the feeders be laid out for negligible voltage drop, which generally is uneconomical.

Usually the feeders are of different intervals, so that the voltage delivered at the centers of the several feeders will vary widely.

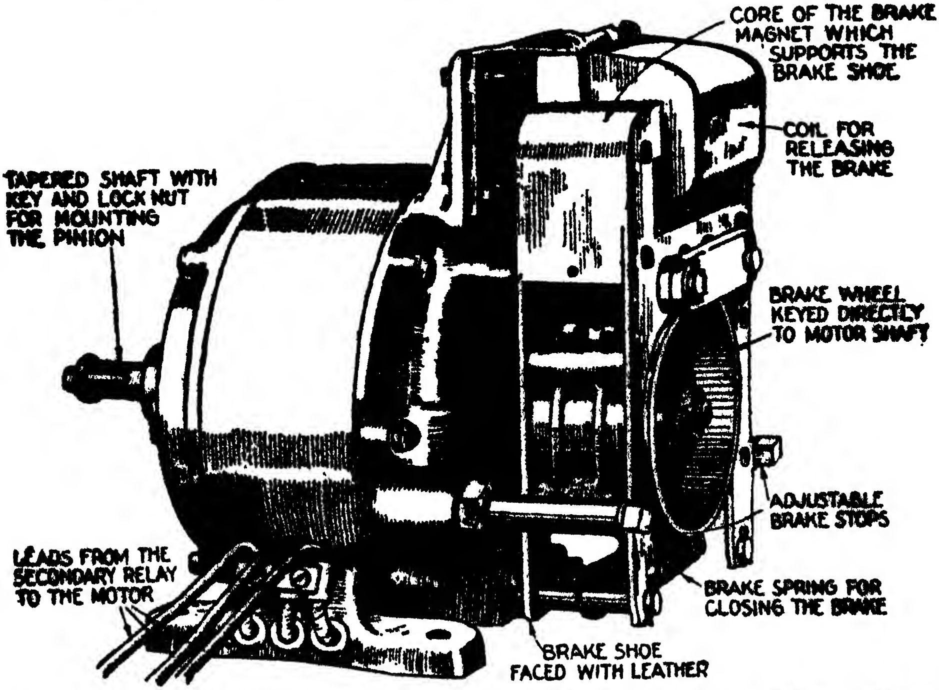


FIG. 4,331.—Westinghouse operating motor for single phase induction voltage regulator showing brake, etc.

It is practically impossible, therefore, to raise or lower the voltage of the station bus so that the voltage at each load center is proportionate to the demands at that center.

In order to provide for satisfactory regulation of the distributing system, it is essential that each feeder be considered as a unit. The system can be made very simple and economical if care be exercised at the time the initial layout is made and many existing plants could probably reduce the distributing cost and improve their service by investigating their

feeding systems with the view toward making them more symmetrical and of uniform regulation.

Recording volt meter charts taken at intervals at various points on each feeder provide a means for detecting voltage irregularities in the feeder, which, if not corrected, may become magnified and not only impair the service but appreciably affect the revenue.

By providing a means for regulating the voltage of the individual feeders, economies may be effected in feeder installation costs by the selection of a smaller sized conductor for the initial installation or for extending existing feeders.

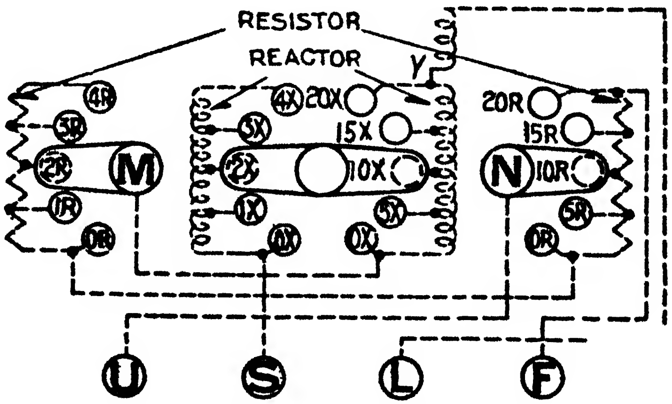


FIG. 4,332.—Connection diagram of Westinghouse neutral line drop compensator.

Furthermore, by maintaining normal voltage at the center of distribution, it is often possible to increase the load on the feeders without making it necessary to reinforce or replace the existing lines.

With slight modification, the various methods of feeder regulation employed with direct current, may be applied to alternating current distribution circuits. For instance, if a non-inductive resistance be introduced in any electric circuit, the consequent drop in voltage will be equal to the current multiplied by the resistance. Therefore, feeder regulation by means of rheostats is practically the same in the case of alternating current as in that of direct current. In the case of the former, however, the effect of self-induction may also be utilized to produce a drop in voltage. In practice, this is accomplished by the use of self-induction coils which are commonly known as reactance coils.

TEST QUESTIONS

1. *Why is voltage regulation important?*
2. *What is the advantage of close voltage regulation?*
3. *Name two types of regulator.*
4. *Of what does an induction regulator consist?*
5. *Describe the operation of an induction regulator.*
6. *What are the effects of revolving the primary coil from the neutral position first in one direction then in the other?*
7. *Name three methods of operating induction regulators?*
8. *What attachment is provided on a motor operated induction regulator?*
9. *Name six auxiliaries used with induction voltage regulator?*
10. *What is a line drop compensator?*
11. *How do single and polyphase induction regulators differ?*
12. *Describe the control apparatus used with polyphase induction regulators?*
13. *What is the difference between a primary and a secondary relay?*
14. *What provision is made in the primary relay to prevent vibration or chattering?*
15. *Why are outdoor voltage regulators necessary?*
16. *Describe the load ratio type of voltage regulator?*
17. *Describe the driving mechanism used with a load ratio regulator?*
18. *Explain how the voltage of alternators is regulated.*

19. *Make a sketch showing elementary connections of an automatic alternator voltage regulator.*
20. *What is a contact making ammeter used for?*
21. *Draw a diagram of two alternator voltage regulators operating in parallel.*
22. *Under what conditions is the parallel operation of alternator voltage regulators used?*
23. *Describe the variable exciter voltage system of alternator voltage regulation.*
24. *How is the voltage of feeders regulated?*

CHAPTER 80

Rectifiers

By definition a rectifier is a device used *to change alternating current into a uni-directional or pulsating current.*

Direct current, in spite of the many advantages of alternating current, has its own numerous and valuable characteristics and uses. Among these might be mentioned battery charging, telephone and telegraph power units, trolley and other city railway lines, interurban and main line railroads, rolling mills, special drives requiring the facility of control made available only by the use of direct current, electro-chemical applications, etc.

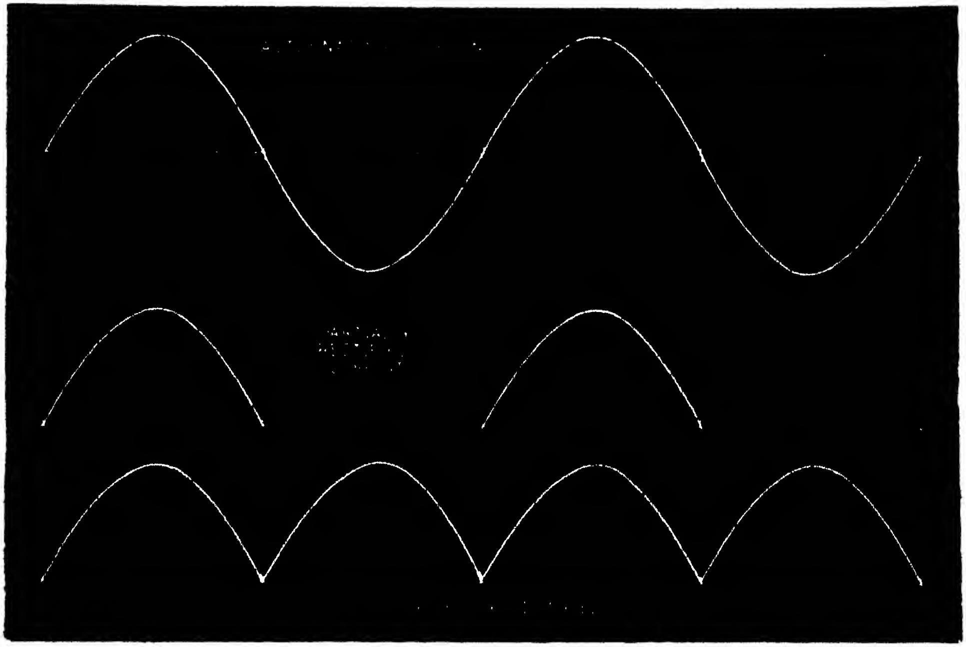
The generation of *d.c.* power at ordinarily used voltages would be very uneconomical due to the small power involved for particular requirements. Furthermore, at the voltages at which it is at present generated and used, transmission of the *d.c.* power over long distances could be accomplished only with considerable losses. The only solution of this problem, therefore, is to generate alternating current, transmit it at high voltages to the site of its application, and there, convert it by the best means available into the desired *d.c.* voltages.

The various kinds of rectifiers may be classed as:

1. Mechanical.
2. Electro-magnetic.
3. Electrolytic.
4. Mercury vapor, or mercury arc.

Mechanical Rectifiers.—By definition, a mechanical rectifier is a form of commutator operating in synchronism with the

alternator and commutating or rectifying the negative waves of the alternating current as shown graphically in figs. 4,333 and 4,335. The essential features of construction are shown in fig. 4,336.



FIGS. 4,333 to 4,335.—Diagrams showing alternating currents, and partial and complete rectification.

One application of a mechanical rectifier is its use on a compositely excited alternator as illustrated on page 1,609.

Electro-Magnetic Rectifiers.—This type of rectifier consists essentially of *a double contact rocker which rocks on a pivot (midway between the contacts), in synchronism with the frequency of the alternating current, so changing the connections at the instants of reversals of the alternating current that a direct current is obtained.*

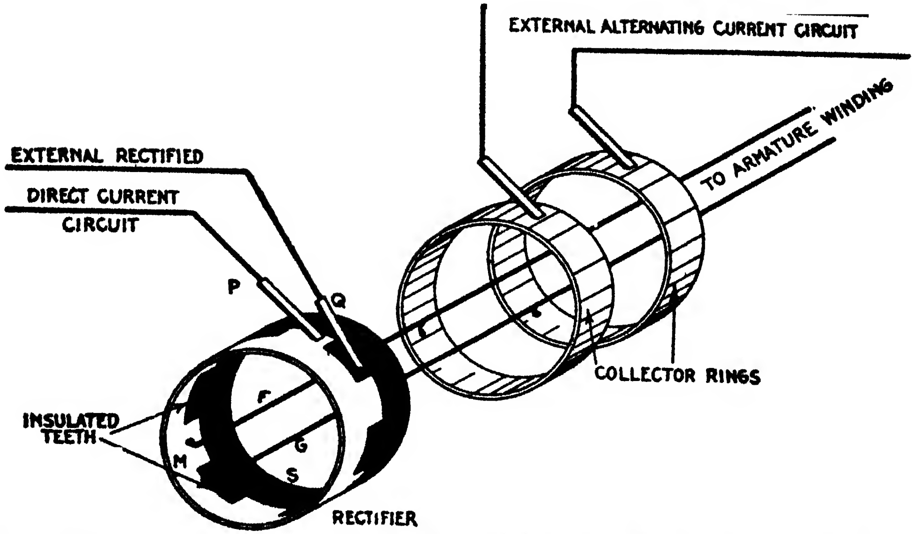


FIG. 4,336.—Mechanical rectifier. The rectifier consists of two castings M and S, with teeth which fit together as shown, being insulated so they do not come in contact with each other. Every alternate tooth, being of the same casting, is connected together, the same as though joined by a conducting wire. There are as many teeth as there are poles. The part M, of the rectifier is connected to one of the collector rings by F, and the part S to the other ring by G

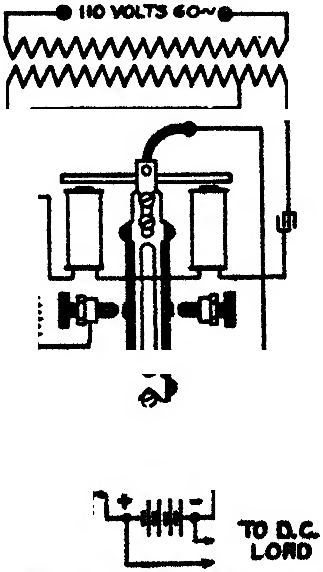


FIG. 4,337.—Circuit diagram of Leich electro-magnetic rectifier, railroad type.

In other words, a vibrating armature makes or breaks a contact at a certain given time in relation to the backward or forward flow of the alternating current. The contacting parts touch only at the time that the current taken from the alternating current system is flowing in the same direction, thus obtaining a pulsating uni-directional current.

If the contacts do not open and close at just the proper instant, arcing will occur at the contacts and trouble will be experienced. From the

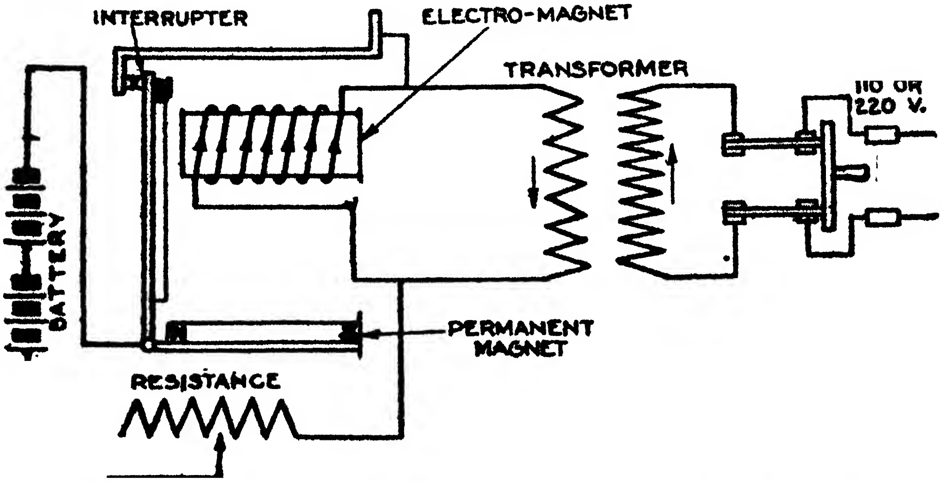


FIG. 4,338.—Diagram of mechanical rectifier. *In operation, a.c.* is passed through the electro-magnet winding. According to direction of current a north pole or a south pole may be set up at the end opposite the iron bar. With the polarity of soft iron bar as in the diagram, it will be attracted whenever the current through the electro-magnet sets up a south pole; repelled, whenever the electro-magnet polarity is reversed (with battery connected as shown) whenever the iron bar is repelled the circuit for the battery is completed and current may flow. When the electro-magnet reverses in polarity the battery circuit is opened and no current can flow. A pulsating charging current is given, useful work being done during one alternation of one cycle only.

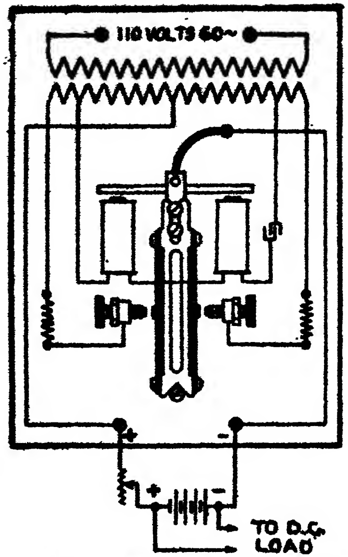
above it will be readily seen that to secure proper and satisfactory results. the vibrating part of the rectifier must at all times be exactly in step with the alternations of the supply mains.

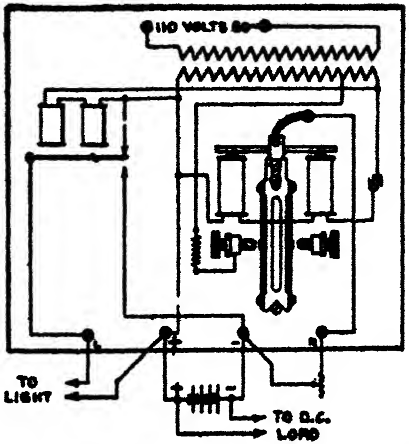
The vibrating element may consist of

1. A vibrating spring or rigidly supported reed,

2. An armature pivoted at the center so as to vibrate over two small magnet coils.

If a vibrating spring or rigidly supported reed be used for the





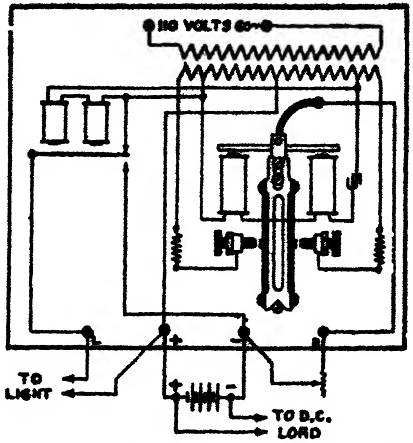


FIG. 4,339—Circuit diagram of Leich full wave electro-magnetic track or battery rectifier. This differs from the half wave type in that it utilizes both halves of the *a. c.* wave and accordingly has an output sufficient to charge 1 lead cell battery at 2 amperes and 2 volts or 2 to 10 cells at one ampere and 4 to 20 volts. This rectifier can, because of its higher charging rate, be used on work consuming a greater amount of current than can be supplied by the half wave type.

FIG. 4,340—Circuit diagram of Leich electro-magnetic rectifier for storage batteries associated with block or crossing signals employing light. In this rectifier is provided a relay through which the lamp circuit is operated from a low voltage tap on the transformer when the power is on. When the power fails, the relay armature makes a back contact which disconnects the transformer circuit and connects the lamp circuit directly to the storage battery.

FIG. 4,341—Leich electro-magnetic double wave rectifier with relay.

moving part, this reed or spring will operate best at one particular speed or frequency.

This speed or frequency is governed by the length, weight, stiffness and other mechanical features of the spring or reed. Therefore, a rectifier having a spring armature will operate properly only when the frequency of the alternating current supply is exactly in tune with the natural frequency of the armature spring or reed. In other words, with rectifiers of the spring armature type, each spring or reed is tuned

to one frequency, consequently a rectifier equipped with a spring armature does not readily respond to changes in frequency of the alternating current supply.

The Leich rectifier shown in the accompanying illustration, is given as an example of the pivoted armature type.

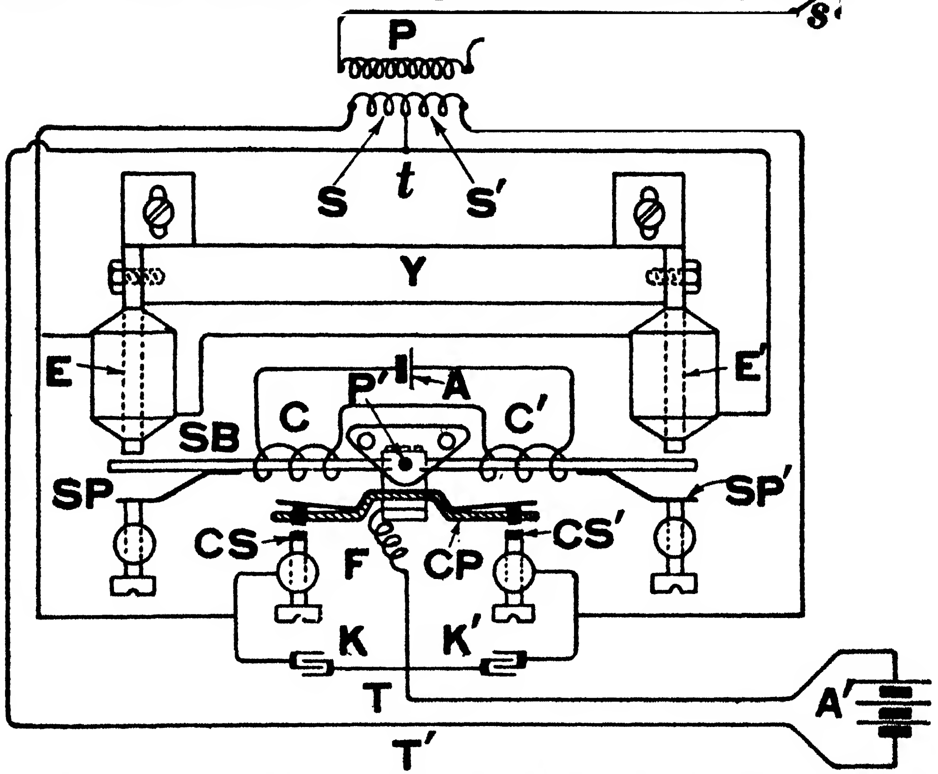
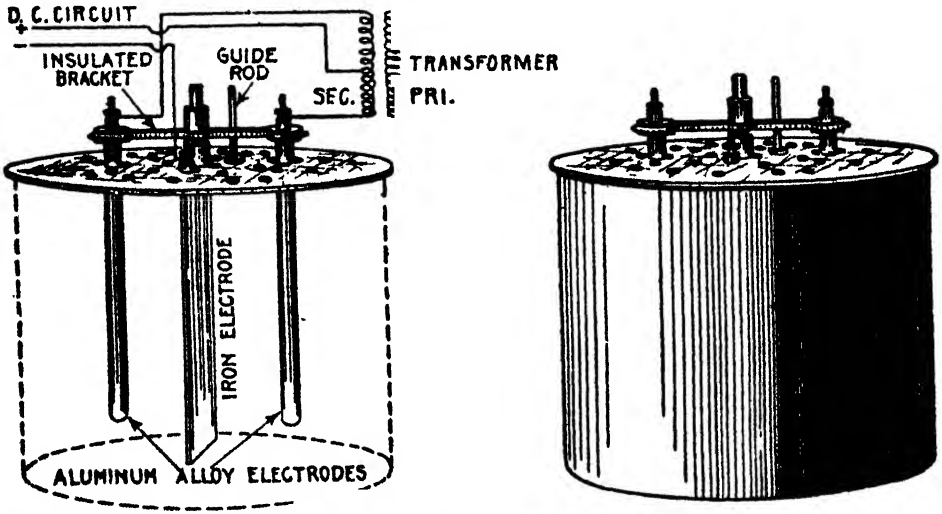


FIG. 4,342.—Diagram of Premier Ampero electro-magnetic rectifier. Owing to the direct current in the magnetizing coils C and C′, one end of SB, will be permanently of north and the other of south polarity; and since the polarities of the poles E and E′, will alternate with the alternations of the transformer secondary current, SB, will rock rapidly on its pivot, and contact will be made by turns with CS and CS′. The purpose of the condensers K and K′, is to reduce the sparking at these points. When contact is made at CS, the direct current terminals T and T′, are connected to the S, half of the secondary winding; and when contact is made at CS′, they are connected to the S′, half. Thus a rectified unidirectional current will flow from T and T′, and it may be used to charge the battery A′, work a small motor or for various other purposes requiring direct current. When the rectifier is used for charging storage batteries, the separate cell A, may sometimes be dispensed with, the winding C,C′, being connected to one of the cells under charge. The rectifier is adjusted to suit the frequency of the supply circuit by altering the distance of the poles of E, and E′, from the ends of the polarized armature SB; and also by changing the tension of SP,SP′, by 1 of the screw studs against which they bear.

In this rectifier, the contacting part is suspended from the armature similar to a clock pendulum. Due to the fact that the armature swings free on its supporting shaft, it can follow the reversal or alternations of the current supply even if there be considerable variation in the frequency.

Electrolytic Rectifiers.—If two metals be placed in an electrolyte and then subjected to a definite difference of pressure, *they will* (under certain conditions) *offer greater resistance to the*



FIGS. 4,343 and 4,344.—Mohawk electrolytic rectifier. To put in commission, clean out the jar. Fill with distilled or rain water. Add six pounds of electro-salts, stir and after all salts are dissolved place the cover in position. The specific gravity of the solution should be 1.125. The middle iron electrode must hang straight down in the solution and not touch either of the other aluminum alloy electrodes. The aluminum alloy electrodes are mounted on an insulated bracket that slides up and down on a ¼″ rod. This rod screws in the hole taped in the middle of the cover. The electrodes give the best results only when perfectly smooth. Should they get rough, covered with a deposit or a white coating, remove from the solution and clean with fine sand paper. Finish with fine sand paper. Form the film again and the electrodes will be as good as new. Clean iron electrode occasionally.

passage of a current in one direction, than in the other direction. On account of this so called valve effect, electrolytic rectifiers are sometimes called "valves."

Aluminum is extensively used for the cathode and lead or polished steel for the other electrode. Metals of low atomic weight exhibit the valve

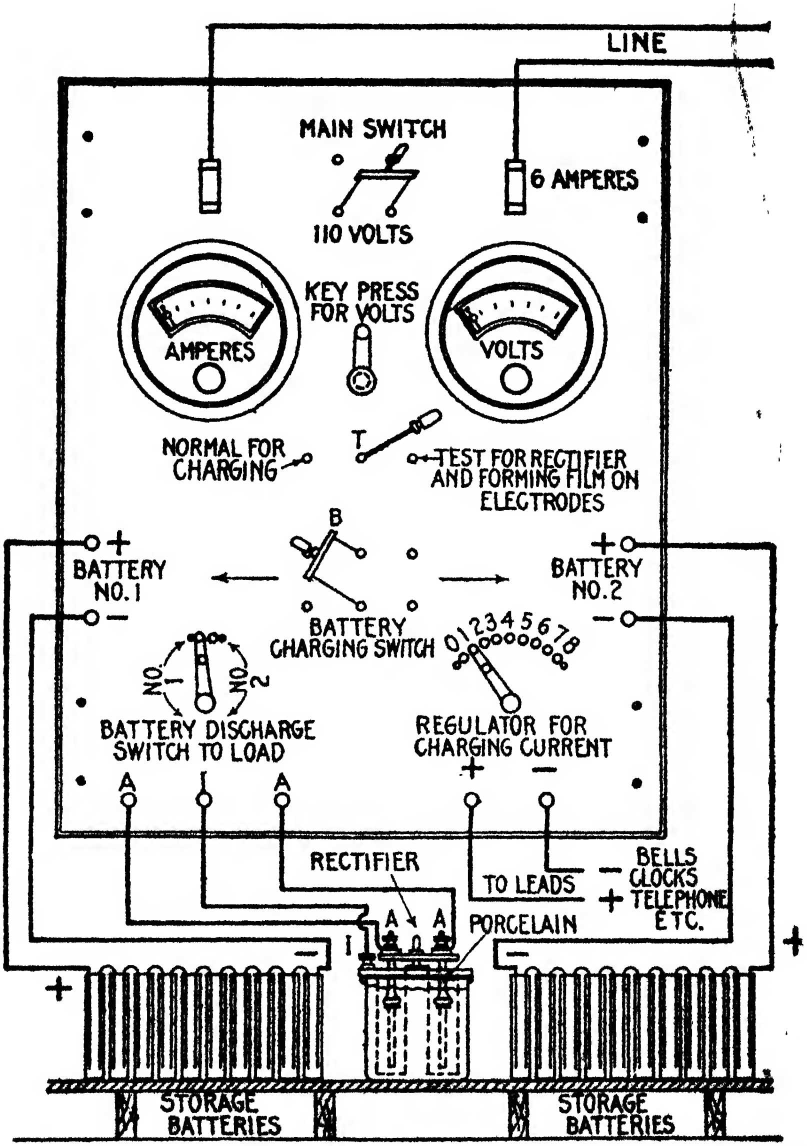
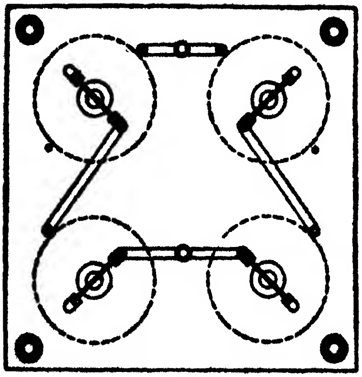
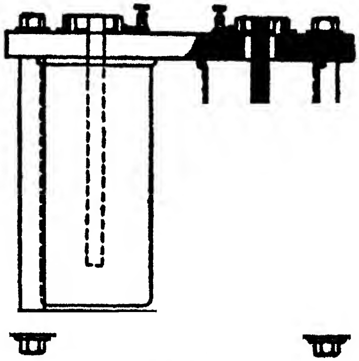


FIG. 4,345.—Mohawk electrolytic rectifier and switchboard; diagram showing connections for charging storage battery. *Operating instructions:* After assembling battery as in fig. 4,343, the *film* must be formed on the aluminum alloy electrodes so that the rectifier will pass current only in the right direction. Open switch B, close switch T, to the right; discharge lever can be in any position; charging regulator lever must be to the extreme left, the zero position; now close main switch M Move regulator lever R, from the zero position to the





FIGS. 4,346 and 4,347.—Two views of Nodon valve. This is an electrolytic rectifier in which the cathode is a rod of aluminum alloy held centrally in a leaden vessel which forms the anode and contains the electrolyte, a concentrated solution of ammonium phosphate. Only a short portion at the lower end of the cathode is utilized, the rest, which is rather smaller in diameter, being protected from action by an enclosing glass sleeve. The current density at the cathode ranges from 5 to 10 amp. per sq. dm. In the larger sizes, the cells are made double, and a current of air is kept circulating between the walls by means of a motor driven fan. In order to utilize both halves of the supply wave, the Gratz method of connection is adopted. The maximum efficiency is obtained at about 140 volts, and the efficiency lies between 65 and 75 per cent., and is practically independent of the frequency between the limits of 25 and 200. Above a pressure of 140 volts, the efficiency falls off very rapidly, owing to breakdown of the film. The pressure difference is high, being over 90 per cent. at full load. Temperature largely influences the action of the valve, and should never exceed 122° Fahr.

FIG. 4,345.—*Text continued.*

first button or contact, let it remain there for a time, ***not less than five minutes; this is important***, as the proper rectification of the current depends on the film formed on the aluminum rods. The ammeter after the first rush of current may not show any current as passing, or it may show a reverse current. In the latter case, leave the contact finger on the first button until the needle comes back to zero. This may take some time, but the needle will eventually come back; it also indicates that the film is properly formed when the needle returns to zero. Move regulator R, to the extreme right step by step and note that the ammeter continues to return to zero, which indicates that the film on rectifier electrodes is formed properly. Move regulator R, to zero, close switch T, to the left in normal charging position. Close charging switch B. To regulate the flow of current through the battery move charging lever R, to the right slowly until ammeter indicates the correct charging current. After the batteries are charged and ready for use, discharge lever can be moved to connect either set of storage batteries to the load terminal. The voltage of the batteries can be read at any time, by pressing the strap key. The discharge lever connects the batteries to the volt meter and it is possible by moving it to measure the voltage of either set of battery, charging or discharging. Trouble in the rectifier demonstrates itself by the solution becoming heated. The condition of the rectifier can be tested any time in a few seconds by opening switch B, and closing switch T, to the right. If the rectifier be in proper condition the ammeter will read zero. And if it be not rectifying and permitting A.C. current to flow through the rectifier, the ammeter will read negative or to the left of the zero. An old solution that is heating and not rectifying properly will turn a reddish brown color.

effect at high differences of pressure, and heavier metals at low differences of pressure.

Illustrating the development of electrolytic rectifiers, the following valves are given as typical examples:

Nodon Valve.—In this valve the cathode is of aluminum or aluminum alloy, and the other electrode, which has considerably more surface, is the containing vessel. The electrolyte is a neutral solution of ammonia phosphate.

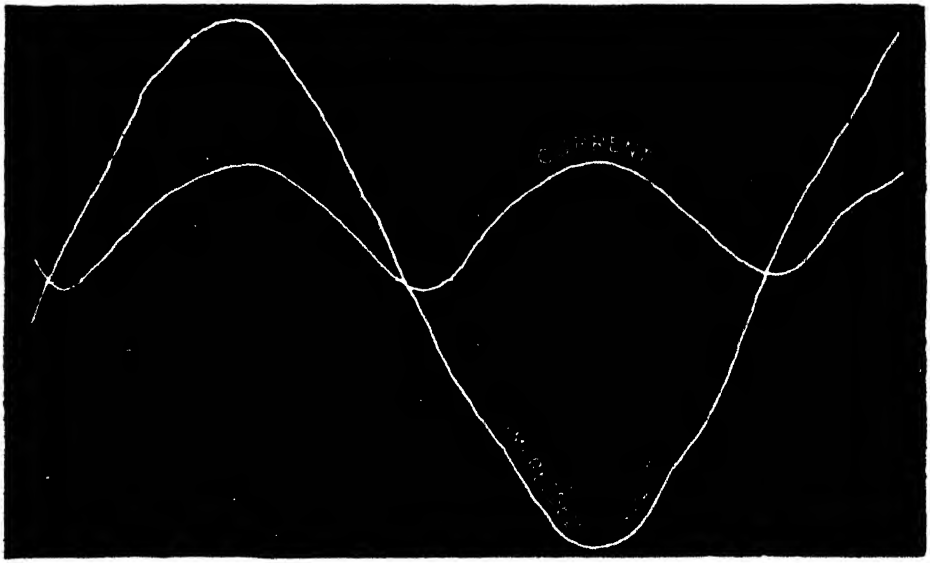


FIG. 4,348.—Oscillograph record from Nodon valve showing original supply voltage and the corresponding pulsating current at the terminals of such a valve.

Its action is due to the formation of a *film* of normal hydroxide of aluminum, over the surface of the aluminum electrode. This film presents a very high resistance to the current when flowing in one direction but very little resistance, when flowing in the reverse direction.

When a Nodon cell is supplied with alternating current the first effect is that half of the wave will be suppressed and an intermittently pulsating current will result as shown in fig. 4,348.

Both halves of the *a.c.* waves may be utilized by coupling a series of cells in opposed pairs.

The efficiency of the film depends upon the temperature.

It should not for maximum efficiency exceed 86 degrees Fahr. There is also a certain critical voltage above which the film breaks down locally, giving rise to a luminous and somewhat disruptive discharge accompanied by a rapid rise of temperature and fall in efficiency.

When an electrolytic rectifier is not in use for some time, the electrodes will lose the film. In such cases the electrodes must be reformed. The loss of film may be prevented by removing the electrodes from the electrolyte and drying them. Water must be added from time to time to

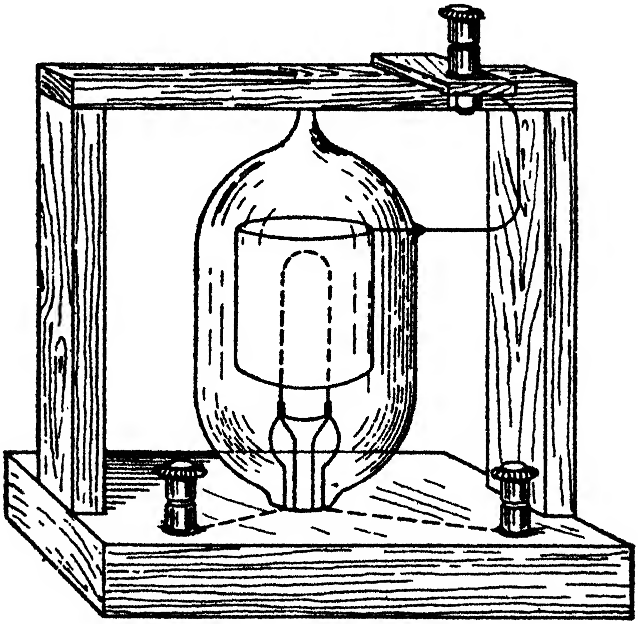


FIG. 4,349.—The Fleming oscillation valve. It depends for its action on the well-known Edison effect in glow lamps. The valve consists of a carbon filament glow lamp with a simple central horseshoe filament. Around this filament inside the exhausted bulb is fixed a small cylinder of nickel, which is connected by means of a platinum wire sealed through the bulb to a third terminal. *The valve is used as follows: The carbon loop is made incandescent by a suitable battery. The circuit in which the oscillations are to be detected is joined in series with a sensitive mirror galvanometer, the nickel cylinder terminal and the negative terminal of the filament of the valve being used.* The galvanometer will then be traversed by a series of rapid discharges all in the same direction, those in the opposite direction being entirely suppressed.

make up for evaporation. This is necessary to keep the solution at the proper density.

Excessive heating of the solution with normal load indicates that the rectifier needs recharging.

A rectifier is passing alternating current when it heats, and when it gives a buzzing sound in the case of very weak solution. Weak electrolyte will eat away the electrodes.

The Audion Valve.—This valve was invented by DeForest in 1900 and is practically identical with the Fleming oscillation valve, the latter being illustrated in fig. 4,349.

Grisson Valve.—In this valve the cathode is a sheet of aluminum,

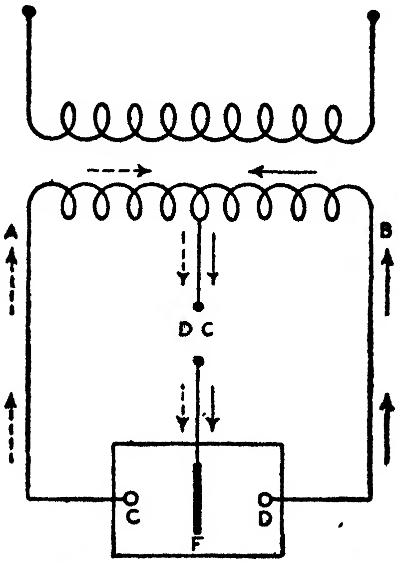
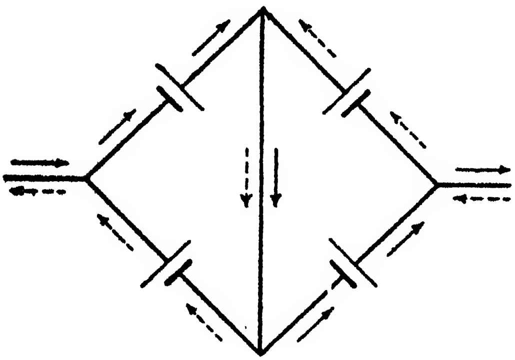


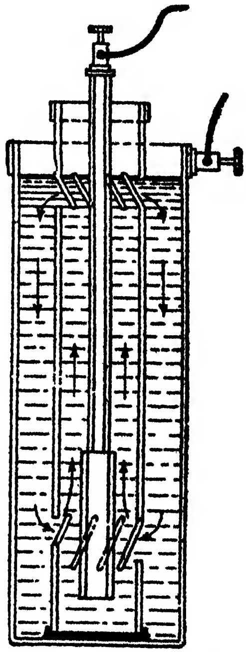
FIG. 4,350.—The Churcher valve. This is of the modified Nodon type. *It differs* from the latter in that it has two cathodes of aluminum and an anode of lead or platinum, suspended in the one cell. This permits the complete utilization of both halves of the supply wave with one cell instead of the four required in the Gratz method. The connections of such a cell are shown in the figure. The secondary of the transformer carries a central tapping, and is connected through the direct current load to the central anode, while each of the cathodes is connected to the ordinary terminals of the transformer itself. The practical limits of the cell are 50 volts direct current, or 130 volts at the transformer terminals AB. F, is the anode; C, cathode I; D, cathode II.

and the anode, a sheet of lead, supported, in the original form, horizontally in a vessel containing the electrolyte, consisting of a solution of sodium carbonate. Cooling is effected by circulating water through metal tubes in the electrolyte itself.

Pawlowski Valve.—This is an electrolytic valve employing a solid electrolyte. It consists of a copper plate which has been coated with a

crystalline layer of carefully prepared copper hemisulphide, prepared by melting sulphur and copper together out of contact with air. The prepared plate is placed in contact with an aluminum sheet and the combination is then *formed* by submitting it to an alternating pressure until sparking, which at first occurs, ceases.





FIGS. 4,351 and 4,352.—The De Faria valve. This is an aluminum lead rectifier. The cathode is a hollow cylinder of aluminum placed concentrically in a larger cylinder of lead, and the whole immersed in electrolyte of sodium phosphate in an ebonite containing vessel. Cooling is effected by promoting automatic circulation of the electrolyte by providing the lead cylinder with holes near its extremities; the heated electrolyte then rises in the lead cylinder, passes out at the upper holes, is cooled by contact with the walls of the containing vessel, and descends outside the lead cylinder. It is claimed that this cooling action is sufficient to allow of a current density of 8 amp. per sq. dm. of aluminum.

Buttner Valve.—It is of the Nodon type employing a cathode of magnesium-aluminum alloy, and probably iron or lead as an anode, with an electrolyte of ammonium borate. Buttner claims that the borate is superior to the phosphate in that it does not attack iron, and will keep in good working condition for longer periods.

Mercury Vapor or Arc Rectifiers.—The terms *vapor* or *arc* applied to rectifiers do not indicate a different principle; the

Westinghouse Company employ the former term and the General Electric Company the latter as a distinguishing title or trade mark.

The Westinghouse or Cooper-Hewitt rectifier is illustrated in fig. 4,353.

This rectifier as developed by Peter Cooper Hewitt for changing alternating current into direct current is the result of a series of careful experiments and investigations of the action going on in his mercury vapor lamp for electric lighting used on direct current circuits only.

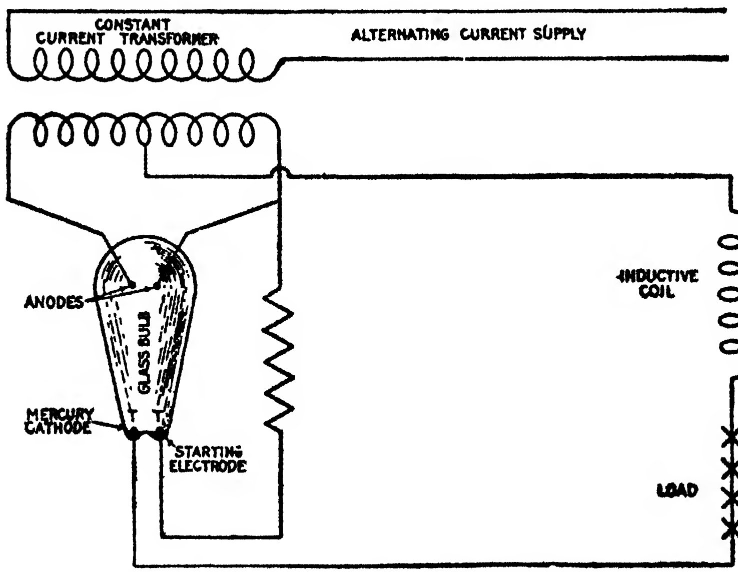


Fig. 4,353.—Cooper Hewitt Mercury vapor rectifier.

The difficulty of operating a lamp on the alternating current circuit lies in the fact that while a current will flow freely through it in one direction, when the current reverses the negative electrode or cathode acts as an electric valve and stops the current, thus breaking the circuit and putting out the light. By following up this new electrical action, Hewitt applied the principle in the construction of a vacuum tube with suitable electrodes, and by using two electrodes of iron or graphite for the positive or incoming current and one of mercury for the negative or where the current leaves the tube, the circuits could be arranged so that a direct

current would flow from the mercury electrode and be used for charging storage batteries, electro-chemical work or operating direct current flame arc lamps.

As shown in the figure, ***the rectifier consists essentially of a glass bulb into which are sealed two iron or graphite anodes and one mercury cathode, and a small starting electrode.*** The bulb is filled with mercury vapor under low pressure. The action of this device depends on *the property of ionized mercury vapor of conducting electricity in one direction only.*

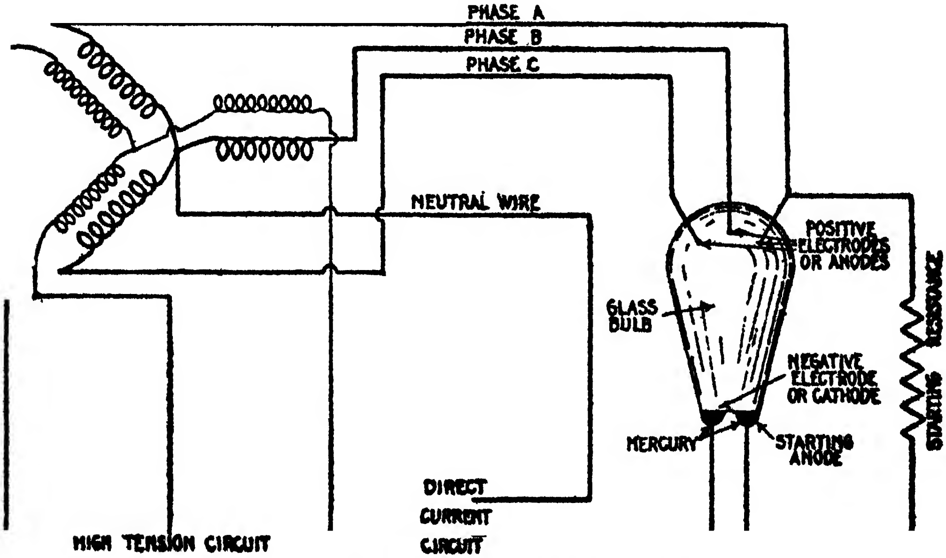
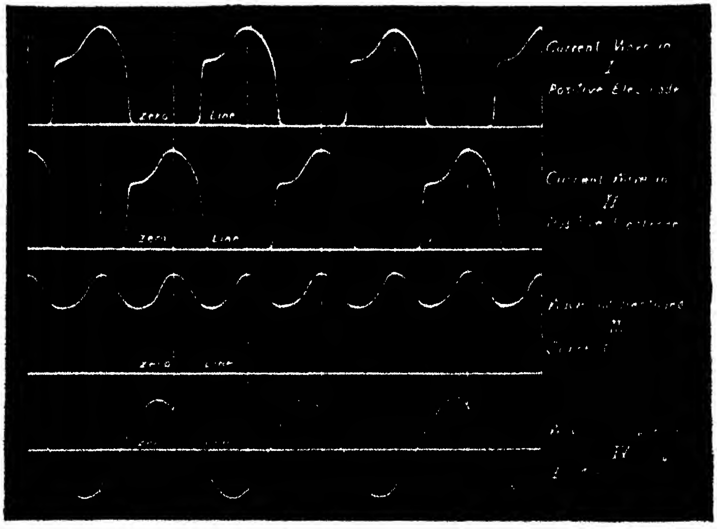


FIG. 4,354.—Three phase mercury arc rectifier. The rectifier bulb is provided with three positive electrodes or anodes, a negative electrode or cathode, and a starting anode, as shown. The three phase leads are connected to the anodes at the top of the bulb, a branch from one phase being brought down to the starting anode, a resistance being placed in the circuit to prevent excessive current on account of the proximity of the two lower electrodes. Since there is always a pressure on one of the three anodes in the right direction, a reactance coil is not necessary. The apparatus is started in the usual way by tilting.

In operation no current will flow until the starting or negative electrode resistance has been overcome by the ionization of the vapor in its neighborhood. To accomplish this, the voltage is raised sufficiently to cause the current to jump the gap between the mercury cathode and the starting cathode, or by bringing the cathode and starting electrode together in the vapor by tilting and then separating them, thus drawing out the arc. When this has been done, current will only flow from the anode to the mercury cathode, and not in the reverse direction.

Fig. 4,355.—Westinghouse-Cooper Hewitt mercury vapor rectifier bulb. It consists essentially of a hermetically sealed glass bulb filled with highly attenuated vapor of mercury, and provided with electrodes. Its operation is fully explained in the accompanying text.



Figs. 4,356 to 4,359.—Diagram of current waves and impressed pressure of Westinghouse-Cooper Hewitt mercury vapor rectifier. The whole of the alternating current wave on both sides of the zero line is used. The two upper curves in the diagram show the current waves

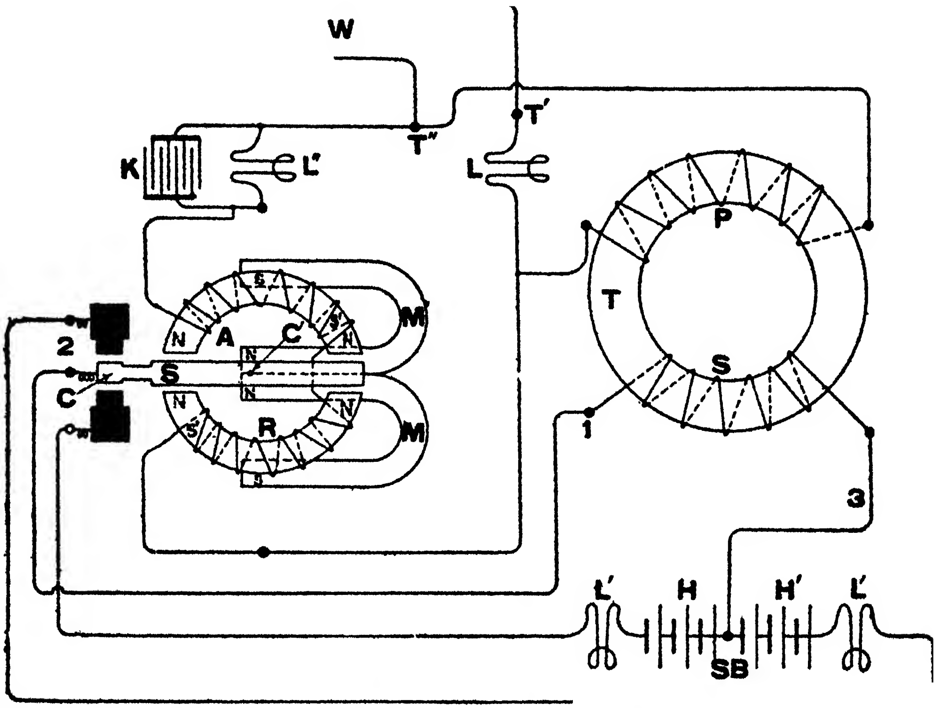


FIG. 4,360.—Diagram of Batten type electro-magnetic rectifier. ***In construction and operation,*** the soft iron core of the relay is in two halves S' S' and the armature A, carrying C, vibrates between their polar extremities. M, M' are two permanent magnets with their like poles together at the center C' where A is pivoted. Supposing these poles are north as indicated, the extremities of A will be south. The south ends of M, M being in juxtaposition with the centers of the soft iron cores S', S' will render their extremities facing the ends of A of north polarity. The windings on S', S' are connected in series with each other, and in shunt with P across the main terminals T', T". Then because of the polarization of A and S', S', the former will vibrate rapidly in sympathy with the alternations of the current. K is a condenser shunted by a lamp resistance L", this being found to improve the working of R.

FIG. 4,356 to 4,359.—*Text continued.*

in each of the two positive electrodes, and the resultant curve III represents the rectified current flowing from the negative electrode. Curve IV shows the impressed alternating current pressure. It is evident that if the part of the wave below the zero line were reversed, the resulting current would be a pulsating direct current with each pulsation varying from zero to a positive maximum. Such a current could not be maintained by the rectifier, because as soon as the zero value was reached the negative electrode resistance of the rectifier would be re-established and the circuit would be broken. To avoid this condition, reactance is introduced into the circuit, which causes an elongation of current waves so that they overlap before reaching the zero value. The overlapping of the rectifier current waves reduces the amplitude of the pulsations and produces a comparatively smooth direct current as shown in curve III. In this way the whole of the alternating current is transformed to direct current because each of the alternations in both directions is alternately rectified.

In order to maintain the action, a lag is produced in each half wave by the use of a reactive or sustaining coil; hence the current never reaches its zero value, otherwise the arc would have to be restarted.

There are two kinds of losses in the tube: 1, *arcing, or leakage from one anode to the other*, and 2, *the mercury arc voltage drop*. This drop does not depend on the load, the energy represented by the drop being converted into heat, which is dissipated at the surface of the containing vessel.

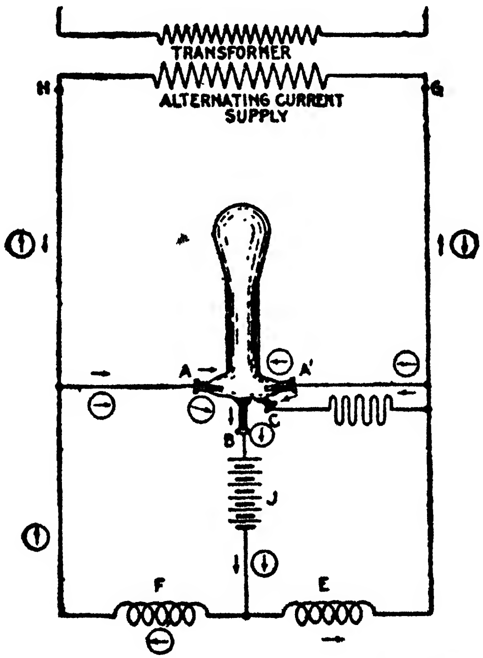
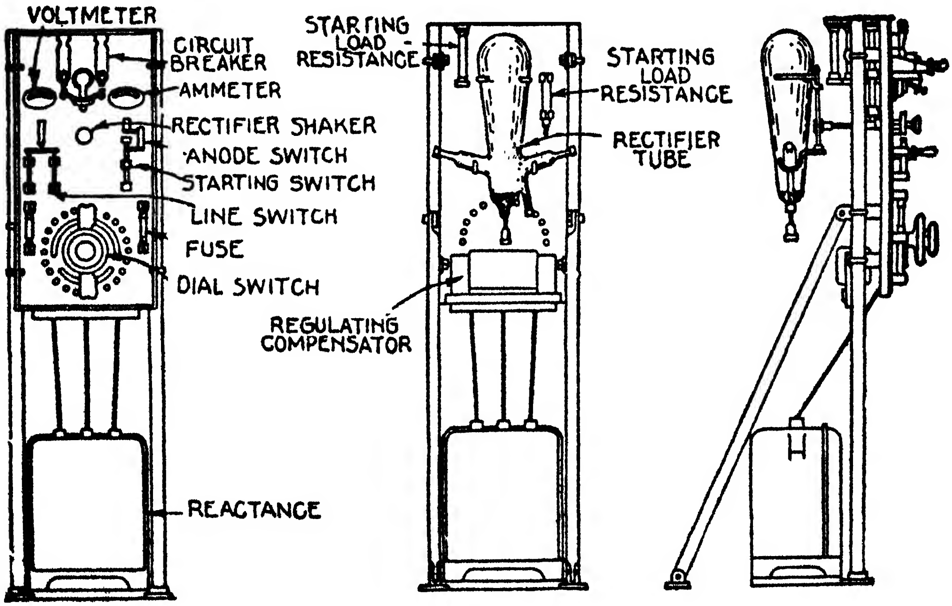


FIG. 4,361.—Elementary diagram of mercury arc rectifier connections. A.A., graphite anodes; B, mercury cathode; C, small starting electrode; D, battery connection; E and F, reactance coils; G and H, transformer terminals; J, battery.

According to Steinmetz, the limit of voltage must be very high, as 36,000 volts has been rectified. The current output is limited principally by the leading-in wires to the electrodes, it being a difficult problem to seal into the glass container the large masses of metal required for the conduction of large currents. Frequency has but little influence. The direct current voltage ranges from 20 to 50 per cent. that of the arc supply. The life of the valve depends somewhat upon its size, being longer in the small sizes and never, with fair usage, less than 1,000 hours.

The construction and operation of the General Electric mercury arc rectifier is shown in fig. 4,361.

The rectifier tube is an exhausted glass vessel in which are two graphite anodes A, A′, and one mercury cathode B. The small starting electrode C, is connected to one side of the alternating circuit, through resistance; and by rocking the tube a slight arc is formed, which starts the operation of the rectifier tube.



FIGS. 4,362 to 4,364.—General Electric mercury arc rectifier outfit, or charging set. The cut shows front, rear, and side views of the rectifier, illustrating the arrangement on a panel of the rectifier tube with its connection and operating devices.

At the instant the terminal H, of the supply transformer is positive, the anode A, is then positive, and the arc is free to flow between A and B. Following the direction of the arrow still further, the current passes through the battery J, through one-half of the main reactance coil E, and back to the negative terminal G, of the transformer.

When the impressed voltage falls below a value sufficient to maintain the arc against the reverse pressure of the arc and load, the ctance E, which heretofore has been charging, now discharges, the current being in the same direction as formerly. This serves to main the arc in the rectifier tube until the pressure of the supply has through zero, reversed, and built up such a value as to cause the anode to have a sufficiently positive value to start the arc between it and the thode B.

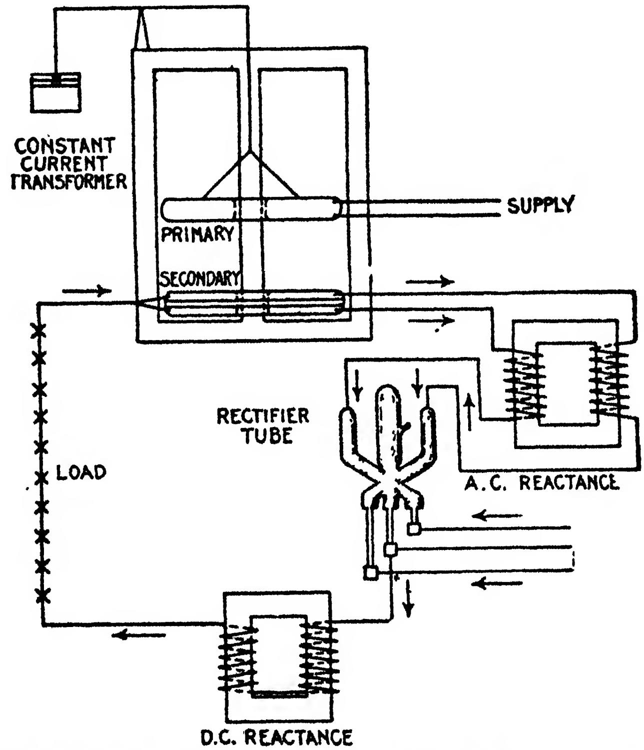


Fig. 4,365.—Diagram showing connections of General Electric series mercury arc rectifier.

The discharge circuit of the reactance coil E, is now through the arc A′B, instead of through its former circuit. Consequently the arc A′B, is now supplied with current, partly from the transformer, and partly from the reactance coil E. The new circuit from the transformer is indicated by the arrows enclosed in circles.

An arc rectifier outfit with its starting devices, etc., is shown in figs. 4,362 to 4,364.

To start the rectifier, close in order named: line switch and circuit breaker; hold the starting switch in opposite position from normal; rock the tube gently by rectifier shaker. When the tube starts, as shown by greenish blue light, release starting switch and see that it goes back to normal position.

Adjust the charging current by means of fine regulation switch on the left; or, if not sufficient, by one button of coarse regulation switch on the right. The regulating switch may have to be adjusted occasionally during charge, if it be desired to maintain charging amperes approximately constant.

In the operation of a mercury arc rectifier a reverse pressure of approximately 14 volts is produced, which remains nearly constant through changes of load, frequency, and voltage. Its effect is to decrease the commercial efficiency slightly on light loads.

Mercury Arc Power Rectifier.—For economic reasons generation and transmission to converting sub-stations at high *a.c.* voltages is essential. Conversion from alternating to direct current, by rotary converters possesses the inherent disadvantages of rotating machinery and the object of the power rectifier is to eliminate these disadvantages, and thereby to provide a plant that can be compared in simplicity to the ordinary static transformer.

Much information on mercury arc phenomena was published during the period 1892-1911, referring, however, only to the mercury arc in glass bulbs, while the theory of single phase rectification was especially treated by Steinmetz and Cooper Hewitt. The latter constructed the first rectifier of a practical design, which was received with much interest for a time, especially in this country.

Steinmetz even gave a theoretical treatment of the two phase rectifier, and discussed the internal phenomena with the help of oscillograms.

After a comparatively long period of inactivity, this problem of rectification by means of the mercury arc valve was again taken up, but this time in Europe. The large power rectifier was to a great extent made possible

NOTE.—*In installing a rectifier* it should be placed in a dry room and care should be taken to avoid dangling wires near the tube to prevent puncturing. If the apparatus be installed in a room of uniform moderate temperature very little trouble will be experienced in starting, while extreme cold will make starting more difficult.

by the construction of an ingenious seal for use with steel tanks. Up to this time only glass vessels could be made sufficiently air tight.

The mercury arc when operating in high vacua has the peculiar property of permitting the passage of a current in one direction only, as previously explained.

In other words, the current is intercepted at each half period, the positive half waves only passing between the two opposing electrodes. The arrangement thus constitutes an electric valve. An explanation for this

FIG. 4,366.—Photograph of mercury arc. The anode is at the top and the cup at the bottom. The arc, as will be seen, is in the form of a halo spread evenly over the surface of the anode while, at the cathode, it centers in the "cathode spot." The intervening space is largely occupied by a spongy looking luminous column which extends down from the anode about three quarters of the way and then stops abruptly, leaving a dark space.

valve action can be given by assuming that the cathode surface which is raised to a state of incandescence at the point where the arc strikes it (known as the "cathode spot") is conducting to electrons in both directions, while the cooler electrode, the anode, conducts only in one direction. From this it is seen that the valve action is almost entirely due to the anode.

The arc takes the form of a luminous column spreading like a halo over the whole surface of the anode and centering in one spot at the cathode, as shown in fig. 4,366, this spot travels at high speed in irregular paths over the surface of the mercury. This rectifying effect is not the peculiar property of mercury but is simply due to the arrangement of two electrodes whereby one (the cathode) is raised to a high temperature (about 3,000 deg. C.) and the other (the anode) is maintained at a temperature (400

deg. C. to 600 deg. C.) below that at which the formation of electrons is possible.

In the rectifier, mercury is used because its vapor can be easily condensed and led back to the cathode without loss. It has been shown that the arc deals only with the positive half of the alternating wave. To make the arrangement commercially possible, both halves must be utilized and this is obtained by connecting in the manner shown in fig. 4,367, which represents a single phase two anode rectifier with step down transformer having a divided secondary, the mid point of which is brought out and forms the negative pole of the direct current system, the cathode forming the positive pole. The best results are obtained where the primary supply is three phase.

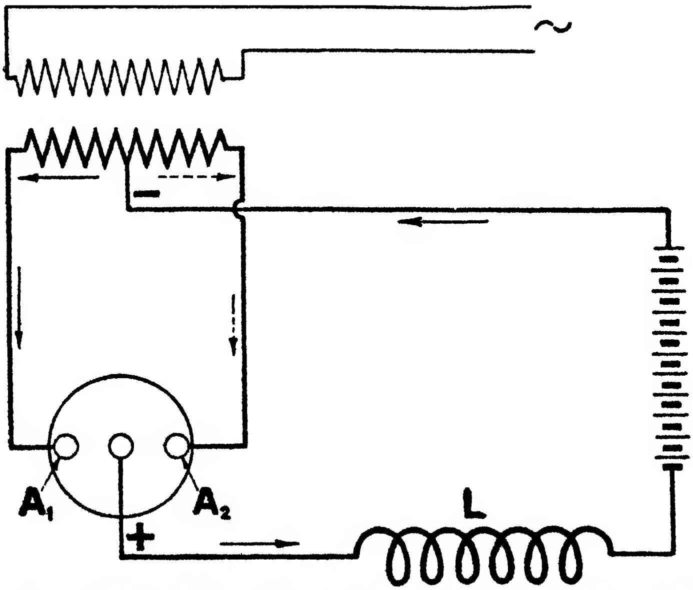


Fig. 4,367.—Single phase two anode mercury arc rectifier and connections to utilise both halves of the *a.c.* wave. Considering first the positive half wave, this induces a current in the left half winding flowing toward anode A_1. During this half period the right half winding is inactive but at a pressure equivalent to that of the left half winding, only of opposite polarity. No current is flowing in this winding due to the valve action of the arc. As the wave passes through zero, the negative half comes into play in the right half winding, inducing a current flowing toward anode A_2. The left half winding is now inactive but at an opposite pressure equivalent to that of the other half. With each cycle this process is continued and both half waves are completely utilized. As it requires only a cessation of the current for a very small fraction of a second to cool the cathode spot sufficiently to extinguish the arc, reactance is inserted in the rectified circuit at L, thus prolonging the wave and preventing it dropping to zero. By making the reactance large enough it is possible to so reduce the undulations in the rectified wave that even a single phase primary supply can be satisfactorily converted and commercially used.

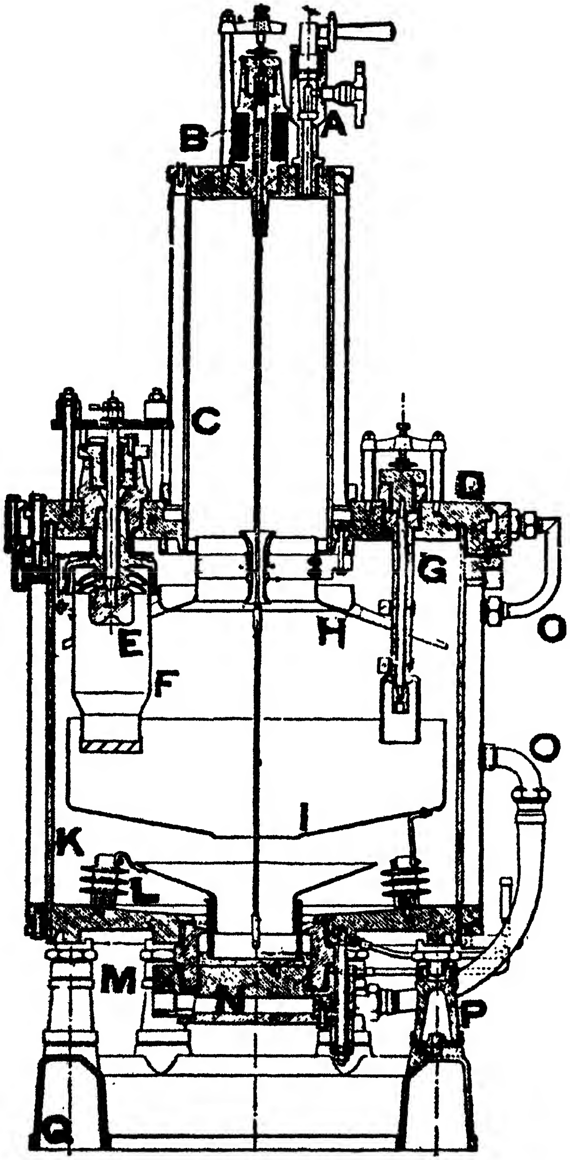
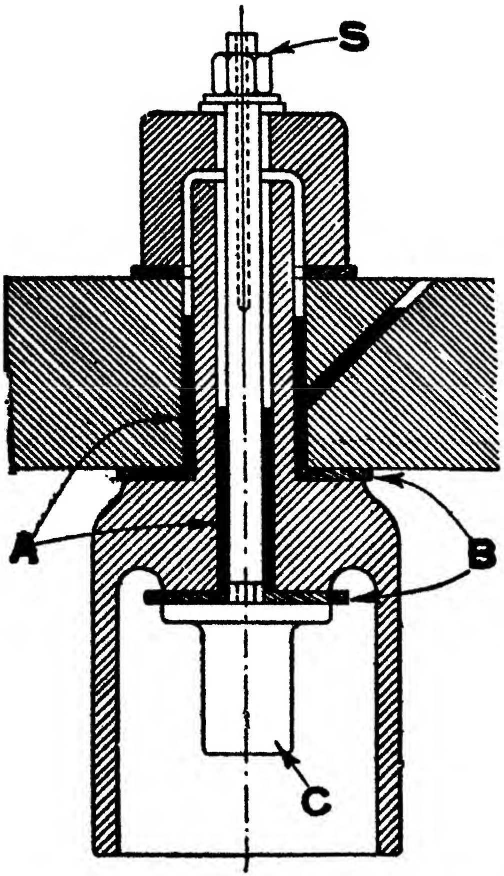


FIG. 4,368.—American Brown Boveri mercury arc power rectifier. *In operation,* the arc works between the main anodes B, and the cathode; it has a well defined path which diminishes the risk of flashing over. At the point of contact of the arc with the mercury, a dense cloud of vapor is given off. The un-ionized portion of this vapor rises between the anodes and finds its way into the condensing cylinder where a reduction in temperature takes place due to the water jacketing and it is re-condensed and drops back in the form of globules into the collector H. From here it runs down the sloping troughs to the sides of the arc chamber and thence back to the cathode so that there is no loss and the mercury need never be replenished. For cooling purposes a small quantity of fairly good water is necessary, that usually obtainable from the city mains being suitable. It first passes through the cathode base, N, from there to the jacketing round the large cylinder and the anode plate by the connections O, after which it passes to the jacket surrounding the condensing cylinder and then out to waste or to a separate re-cooling system.



For the successful operation of the rectifier, high vacua are essential, the normal working range being .01 to .001 mm. of mercury. The first problem therefore that had to be solved in the manufacture of the mercury arc power rectifier was the production of large steel cylinders that would be at once accessible and gas tight. The mercury seal was finally adopted as giving the best results. Its construction is shown in fig. 4,369.

A mercury arc power rectifier is shown in fig. 4,368.

FIG. 4,369.—Mercury seal of American Brown Boveri mercury arc power rectifier. *It consists of* mercury and asbestos for the hotter portions and mercury and rubber for the cooler parts. The mercury is at A and the asbestos at B. As a sealing medium mercury has the advantage that should any filter inward it can only find its way to the cathode and will not interfere with the operation of the plant.

The major portion is the large welded steel cylinder K, in which the arc operates and above it is the narrower condensing cylinder C. These two cylinders are connected by the heavy anode plate D, while the lower portion of the arc chamber is closed in by the plate M, in the center of which the cathodc is located.

The condensing cylinder is closed at its top by a plate carrying the ignition coil B. The rectifier as a whole, is mounted on the insulators P, these in their turn being carried on the foundation ring Q. There are six

main anodes E, and two auxiliary anodes G, placed in a circle around the anode plate.

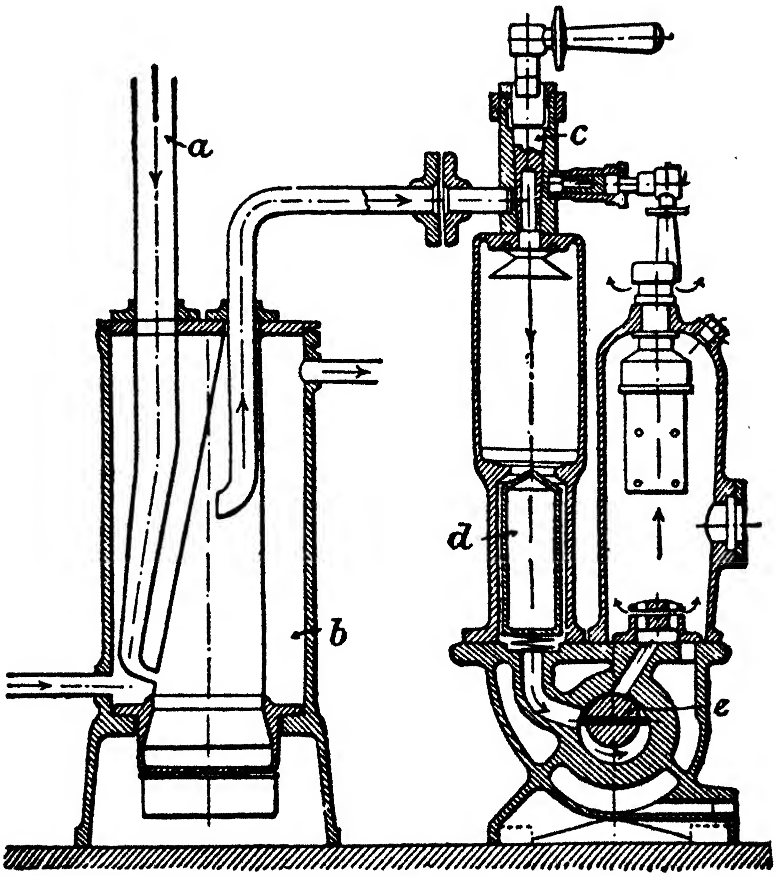


FIG. 4,370.—Two stage vacuum pump of American Brown Boveri mercury arc power rectifier. *It consists of* a high vacuum mercury pump in series with a rotary oil immersed pump. The latter pump is direct coupled to a ⅓ *h.p.* motor and is capable of creating a vacuum equivalent to about .02 mm. of mercury, the final reduction to .001 mm. of mercury and below being obtained by means of the mercury pump. The pump has at its base in the chamber *b*, a pool of mercury which is heated by an electric heater located immediately below. *In operation*, the mercury pump works on the injector principle, this action being produced by the vapors rising from the boiling mercury and in doing so sucking the air and gases down the pipe *a*, connected to the upper portion of the rectifier cylinder. The conical section of the mercury pump is water jacketed so that, as the mixture of vapor and gas rises, the vapor is recondensed and drops back into the pool at the bottom while the gas is drawn off by the rotary pump as indicated by the arrows and then discharged to atmosphere. The rotary pump has a non-return valve *d*, which operates in the event of the pump shutting down and thus prevents the oil and air finding its way into the stationary pump and rectifier.

The auxiliary anodes serve to maintain the arc when the load drops to a very low level (about 40 amps). They may be said to constitute a single phase rectifier within a six phase one, because they are connected externally with a small exciting transformer providing about ½ *kva.* which keeps up the temperature of the cathode spot.

The mid point of the exciting transformer is brought out as in the case of the main transformer and connected through a resistance and small reactance to the cathode—the former limits the current consumed while

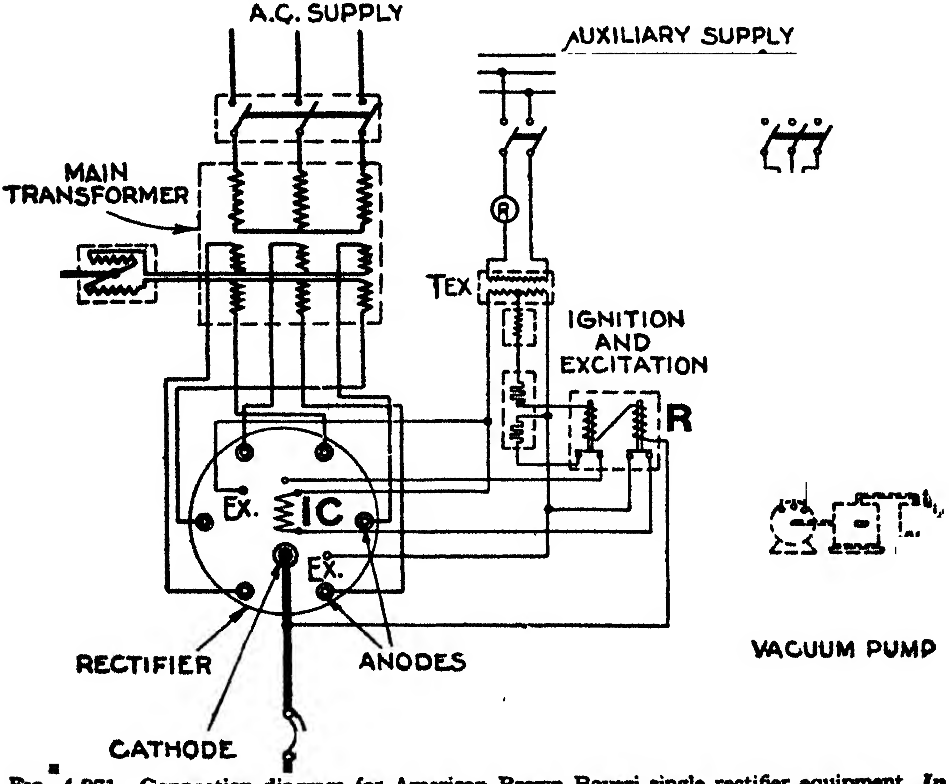


FIG. 4,371—Connection diagram for American Brown Boveri single rectifier equipment. *In operation,* when the main transformer is energized, the primary switch of the excitation transformer Tex, closes at the same time, thereby completing the circuit of the ignition coil IC. This brings down the ignition anode until it touches the mercury bath of the rectifier. The circuit of coil IC, is now opened, due to the current passing down the rod to the ignition anode, which causes the right hand contacts of relay R, to open. The ignition anode is now drawn up by a spring acting in opposition to coil IC, and at the point of rupture with the mercury an arc is started. As the two excitation anodes Ex, are already charged, an arc now starts from them to the cathode. The excitation current strength being greater than that of the ignition current the second part of relay R, operates and its contacts are opened, thereby extinguishing the ignition arc and leaving the rectifier ready to be loaded as required.

the latter insures that the auxiliary arc will not drop to zero at each half period.

The main anodes are screwed to the anode bolts which convey the current to them, the transformer connections are brought to lugs fitted to the upper part of these bolts. Specially designed insulators separate the anodes from the anode plate.

Mercury arc power rectifiers are made in various sizes with ratings from about 150 to 2,000 *kw.* at voltages up to about 1,800 volts. For higher *d.c.* voltages up to 6,000 volts, the current ratings are somewhat reduced.

For a rectifier layout in its simplest form there is only one important auxiliary provided, namely, the vacuum pump set, as shown in fig. 4,370.

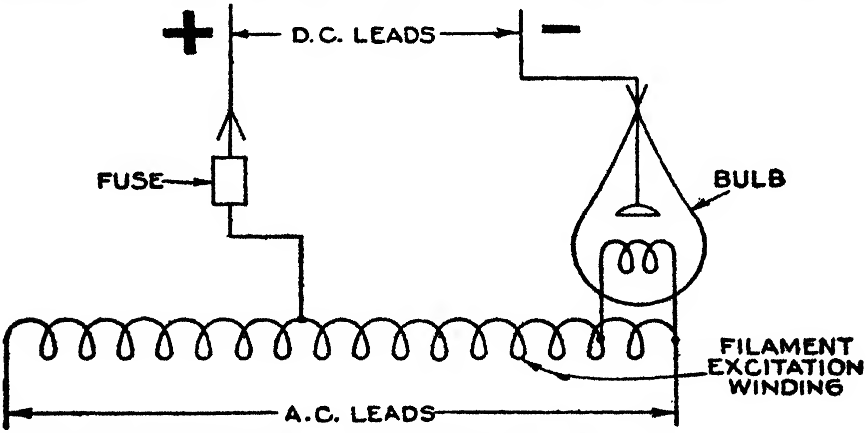


FIG. 4,372.—Half wave Rectigon schematic diagram of connections.

From what has already been said, it will be appreciated that a high vacuum is absolutely essential to the satisfactory operation of the plant.

For the ignition of the arc, alternating current is now employed which has enabled the plant to be materially simplified. The diagram, fig. 4,371 shows the ignition and excitation circuit.

Argon Gas Bulb Rectifiers.—Instead of putting mercury in an exhausted glass bulb, argon gas may be used.

Typical argon gas bulb rectifiers are these made by the Westinghouse Company and General Electric Company under the trade names "Rectigon" and "Tungar" respectively.

The Rectigon outfit consists essentially of a transformer for converting the voltage to the proper value, and a bulb for rectifying. The bulb is a glass envelope, containing an anode and a cathode in the shape of a filament, surrounded by an atmosphere of pure argon. Leads to the anode and cathode are sealed through the glass walls of the bulbs. For convenience of installation, the filament leads are connected to the terminals of a screw base.

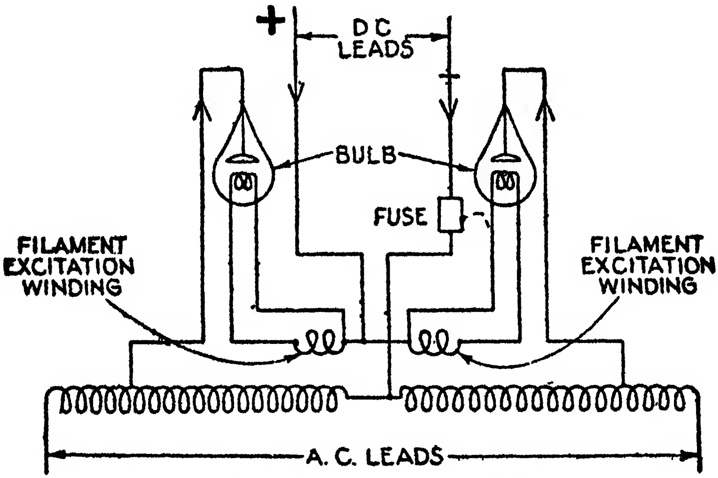


Fig. 4,373.—Full wave Rectigon schematic diagram of connections.

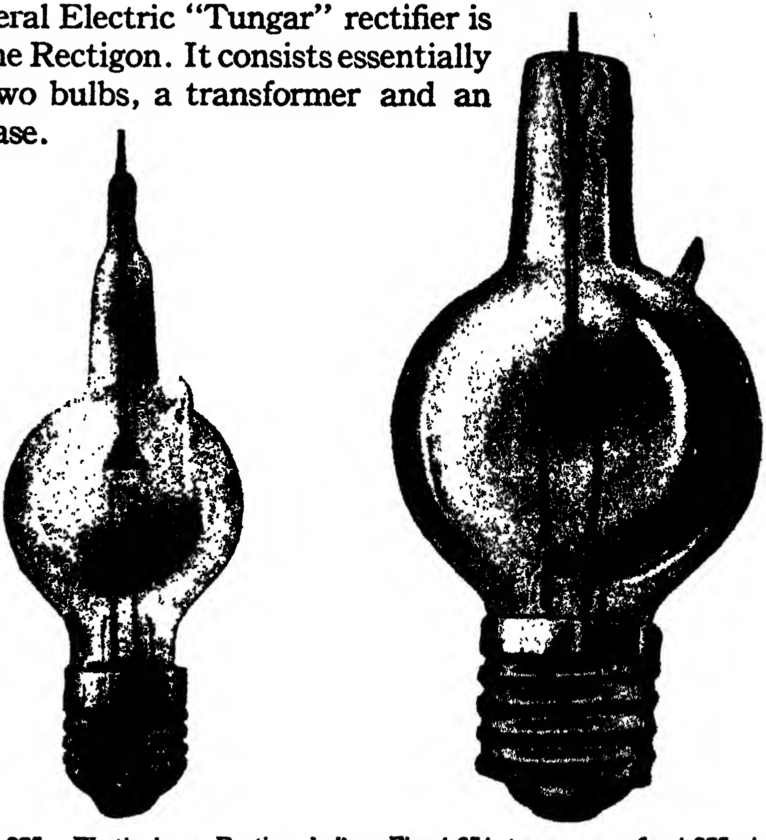
When alternating current voltage is applied to the transformer, the filament of the bulb is heated to incandescence by current from a special winding on the transformer. At incandescent temperature, the filament emits electrons which, by collision with the molecules of the gas, ionize the gas and provide the means of current flow from the anode to the

NOTE.—*Argon gas.* This gas forms rather less than one per cent of the atmosphere. Its presence in the air was first indicated by the fact that a liter of nitrogen prepared from air was found to weigh heavier than a liter of pure nitrogen obtained in other ways. It can be obtained by passing electric sparks through air in presence of caustic potash, and gradually adding oxygen until all the nitrogen has been converted into potassium nitrite and nitrate. Atomic weight, 40. Has a characteristic spectrum, a monatomic molecule. It appears to be incapable of entering into chemical combination with any other element or compound whatever.

cathode. Since the anode remains at a comparatively low temperature, current cannot flow in the reverse direction.

The voltage of the secondary of the transformer is applied to the load through the bulb and due to the valvelike action of the bulb, current is permitted to flow in only one direction.

The General Electric "Tungar" rectifier is similar to the Rectigon. It consists essentially of one or two bulbs, a transformer and an enclosing case.



FIGS. 4,374 and 4,375.—Westinghouse Rectigon bulbs. Fig. 4,374, two ampere; fig. 4,375, six ampere. The small portable Rectigons are designed to charge single batteries in homes and private garages In these outfits the transformer secondary voltage and internal reactance are so chosen to give a charging current not far from the rated values under any conditions of line or battery within reasonable limits without any change in connections or any adjustment for different conditions. The application is limited to lines of voltage variation from 100 to 130 volts and to batteries of between 1 and 48 cells. Within these limits the charging current varies from 20% above the rated value to about 50% below. Thus, with a line voltage 10% above normal and charging 3 cells the current will be approximately 20% above the rated value, and with a line voltage 10% below normal and charging 6 cells, the current will be approximately 50% of the rated value. The charging current does not vary appreciably during charge.

The bulb is similar in appearance to an incandescent lamp. A low voltage filament, the *cathode*, and one or sometimes two carbon *anodes* are used for electrodes. The bulb is filled with argon gas.

When the filament is energized the space between the electrodes acts as an electric valve of low resistance, allowing current to flow only from anode to cathode. Therefore, only uni-directional or direct current can flow from the battery charger. The transformer serves three purposes: First, it adjusts the voltage of the alternating supply to that required by the batteries; second, it furnishes a separate source of excitation for

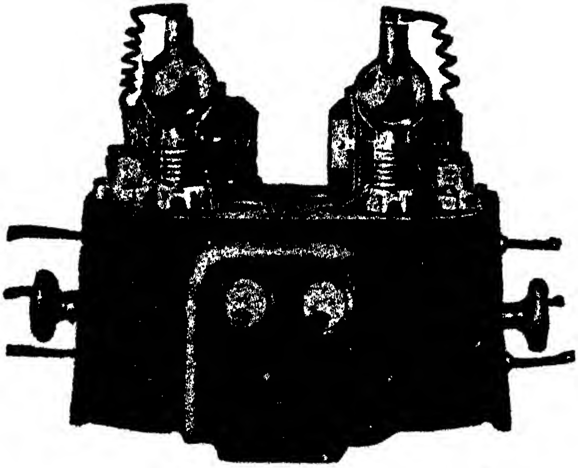
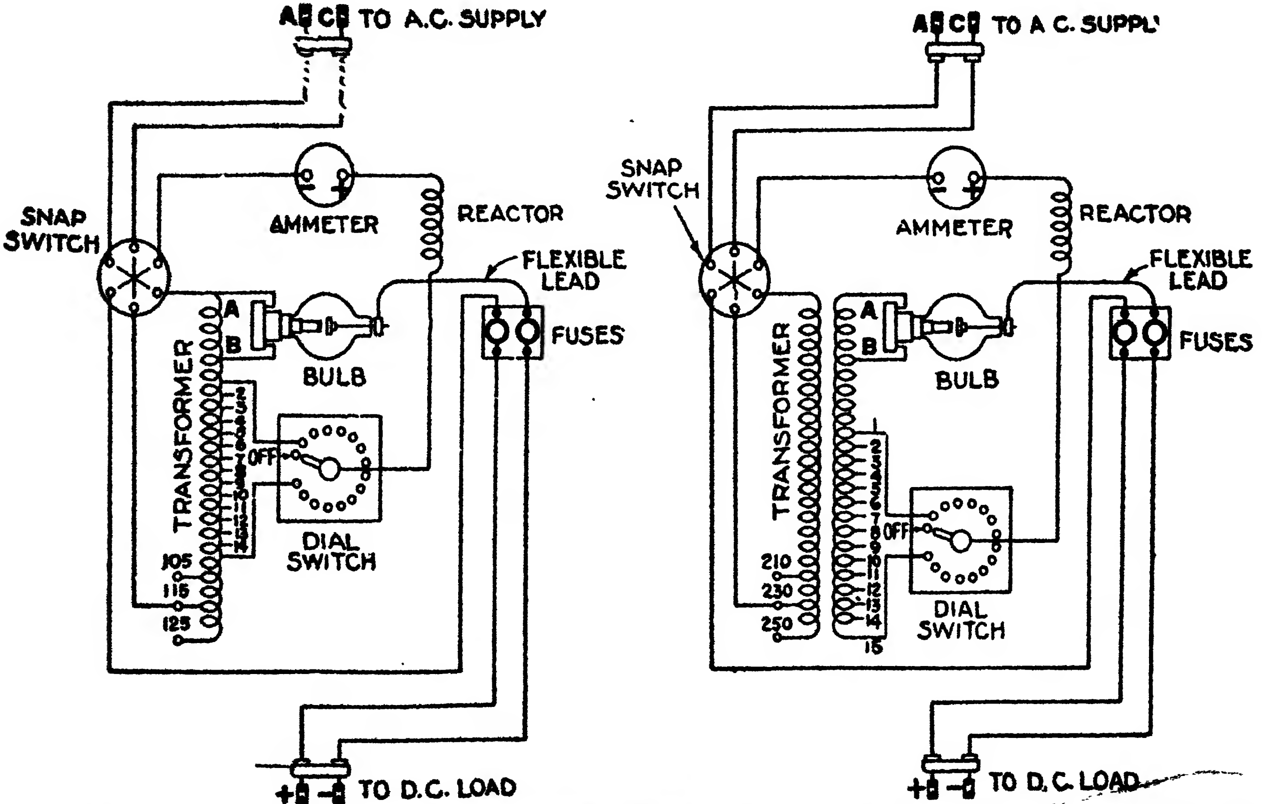


FIG. 4,376.—Westinghouse 12 ampere, 75 volt, Rectigon rectifier with cover removed showing bulbs, etc. By means of the arrangement of the *d.c.* leads, the user is given the choice of three combinations for charging batteries, as there are always two circuits available. The first combination will charge two groups, of from one to ten batteries each, at a six ampere rate. Or, by turning the regulating handle to the off position, it is possible to eliminate one group. A second rearrangement of the external connections permits one to charge a maximum of ten batteries at the rate of 12 amperes. The third combination is an arrangement of batteries into three groups so that the current going into one group will equal the sum of the currents in the other two groups. In this manner it is possible to give a high charging rate to a special group of batteries and at the same time charge two other groups at a low rate.

the filament; and third, it insulates the batteries from the supply current.

Various battery voltages are used. 24 and 48 volt systems predominate, although 12 volts is often used on small and 110 volts on large systems.

Bulb Rectifier Troubles.—Typical of the characteristics of operation of bulb type rectifiers, the following troubles relating



Figs. 4,377 and 4,378—Connection diagram of Westinghouse Rectigon rectifiers. Fig. 4,377, auto transformer type; fig. 4,378, insulating transformer type

in particular to Tungar rectifiers, with their remedies are given.

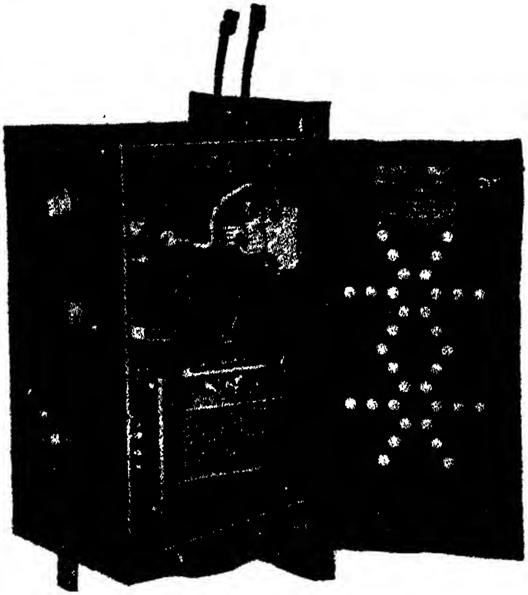
If, on turning on the dial switch, the bulb do not glow:

1. See whether the *a.c.* supply be on;

2. Examine the supply line fuses. If these be blown or be defective replace them with 10 ampere fuses for a 115 volt outfit or with 6 ampere fuses for a 220 volt outfit;

3. Make sure that the bulb is screwed well into the socket;

4. Examine the contacts inside the socket. If they be tarnished or dirty, clean them with sandpaper;



Figs. 4,379 and 4,380.—Westinghouse 6 amperes, 75 volts Rectigon battery charger for public garages and battery service stations. Fig. 4,379, charger closed; fig. 4,380, charger open showing construction.

5. Try a new bulb. The old bulb may be defective;

6. Have the switch arm make good contact on the regulating switch.

If the bulbs light, but no current show on the ammeter:

1. Examine the connections to the batteries, and also the connections between them. Most troubles are caused by imperfect battery connections;

2. Examine the fuse inside the case. If this be blown or defective, replace it with a 12 ampere fuse;

3. See that the clip is on the wire of the bulb;

4. The bulb may have a slow leak and therefore may not rectify. Try a new bulb.

If the current on the ammeter be high and cannot be reduced:

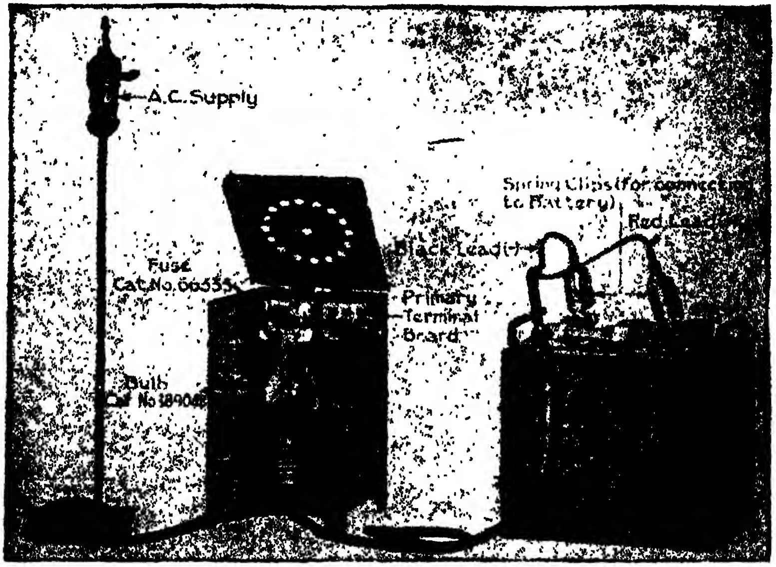


FIG. 4,381.—General Electric Tungar battery charger, home type, for lead batteries. 5 ampere charging rate for 3 cells or 3 ampere charging rate for 6 cells. This type of Tungar is especially adapted for charging radio batteries. The number of ampere hours replaced should be about 30% higher than those taken out of a battery. *For example,* if a 3 tube receiving set (1 ampere per tube) be operated 3 hours, the battery will deliver 9 ampere hours. The Tungar should be operated approximately 2½ hours or a total of 12 ampere hours to replace this amount of discharge. Keep the battery in a fully charged condition at all times. Always have the leads from the battery to the radio set disconnected when charging. The radio set is grounded, and trouble will occur if these instructions be not followed. Always pull the attachment plug out of the socket. Never merely turn off the socket switch when discontinuing charging. Make the detector filament connections direct to the battery and not to the Tungar leads. A safe arrangement is to have a small double pole, double throw switch, the battery being connected to the blade terminals, the Tungar to the terminals on one end and the bulbs to the terminals on the other end.

1. The ammeter may be sticky; tap it lightly with the hand. The ammeter will not indicate the current correctly if the pointer be not on the zero line when the Tungar is not operating. The pointer may be easily reset by turning slightly the screw on the lower part of the instrument;

2. Be sure that the batteries are not connected with reversed polarity;

3. The *a.c.* supply may be abnormally high. Make sure that the primary connection is made to the tap nearest to the supply voltage. Always keep a spare bulb on hand that has been tested for at least one complete charge before being placed in reserve.

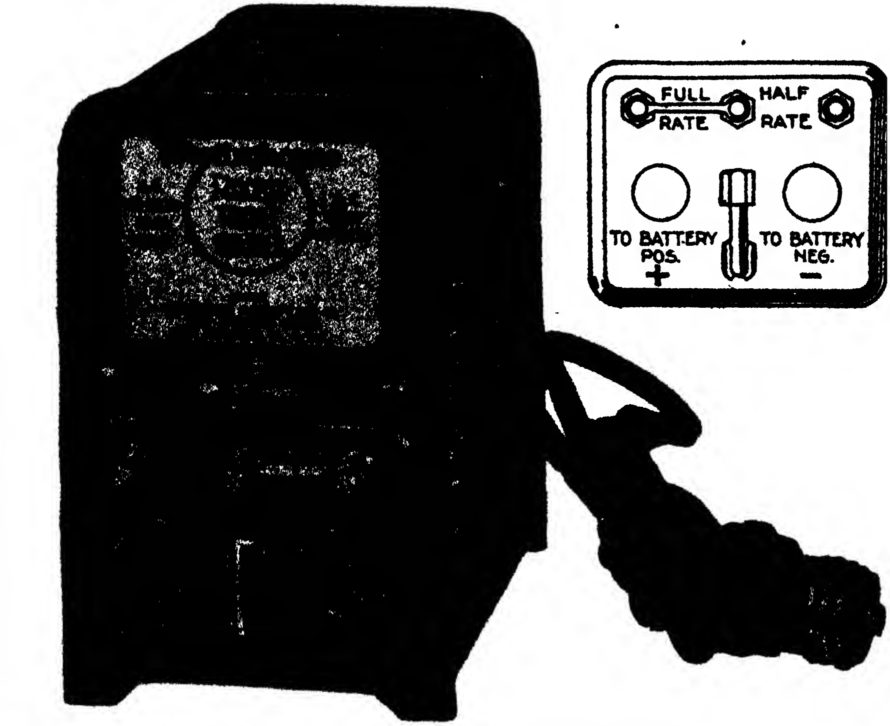


FIG. 4,382.—Westinghouse "Rectox" dry junction trickle charger.

FIG. 4,383.—Connection plate of Rectox dry junction trickle charger. This outfit will charge a 6 volt storage battery at a maximum rate of approximately .75 ampere continuously and provision is also made for charging at a .4 ampere rate if desired. *In charging,* it is merely necessary to connect the battery to the charger by means of short copper wires, and then plug the *a.c.* lead into any convenient light socket. The position of the link connector on the front of the outfit determines whether half or full rate charging will be necessary to select the proper terminals, which are very plainly marked, in order to obtain the charging rate desired.

Dry Junction Rectifier.—This type rectifier was introduced with the idea of avoiding electrolyte, gas, or vacuum as employed in the rectifiers just described. The rectifier of this type here described is made by the Westinghouse Company under

the trade name "*Rectox.*" This outfit consists chiefly of a suitably designed transformer and copper oxide rectifying elements enclosed in a sheet steel case.

The rectifying element consists of copper discs or washers, one side of which has been treated at high temperature to collect a coating of copper oxide. These discs are separated from each other by a lead washer to

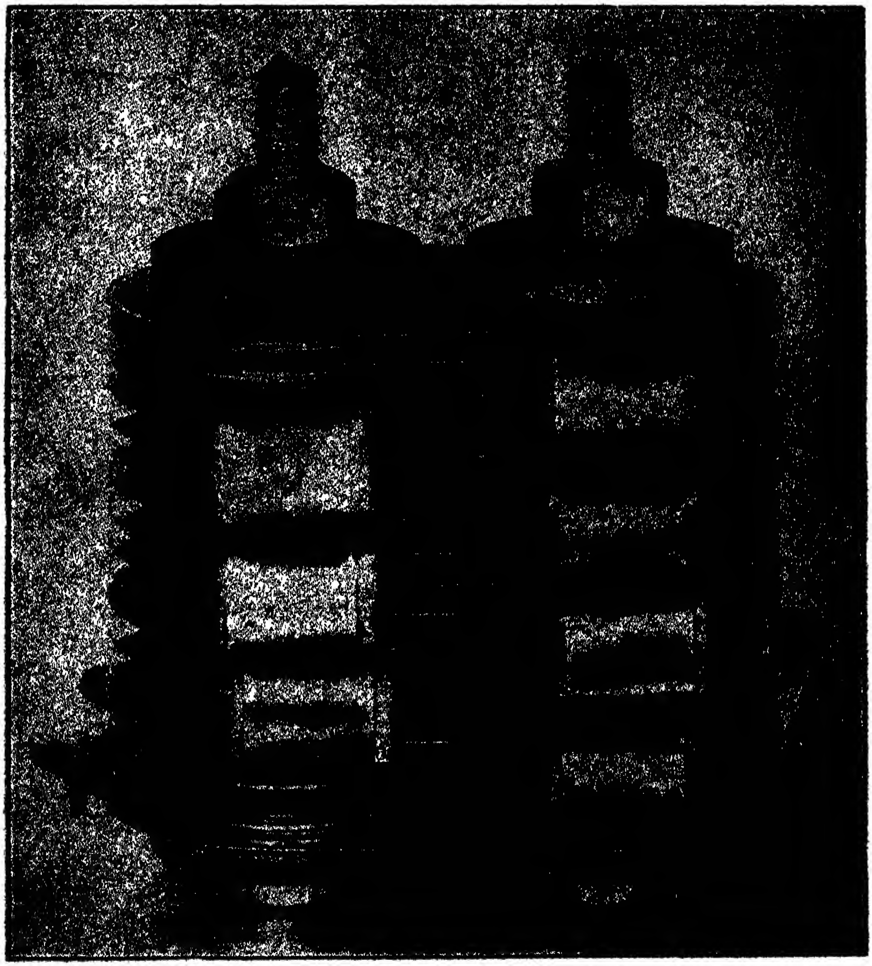


FIG. 4,384.—Westinghouse dry junction rectifier unit consisting of treated copper discs as described in the accompanying text.

furnish good contact. The *d.c.* terminals, fuse and charging rate selector studs are located at one end of the outfit and all parts plainly marked.

The two standard methods of connecting rectifiers for full wave rectification are shown in figs. 4,385 and 4,386.

FIGS. 4,385 and 4,386.—Arrangement of dry junction rectifier for full wave rectification.

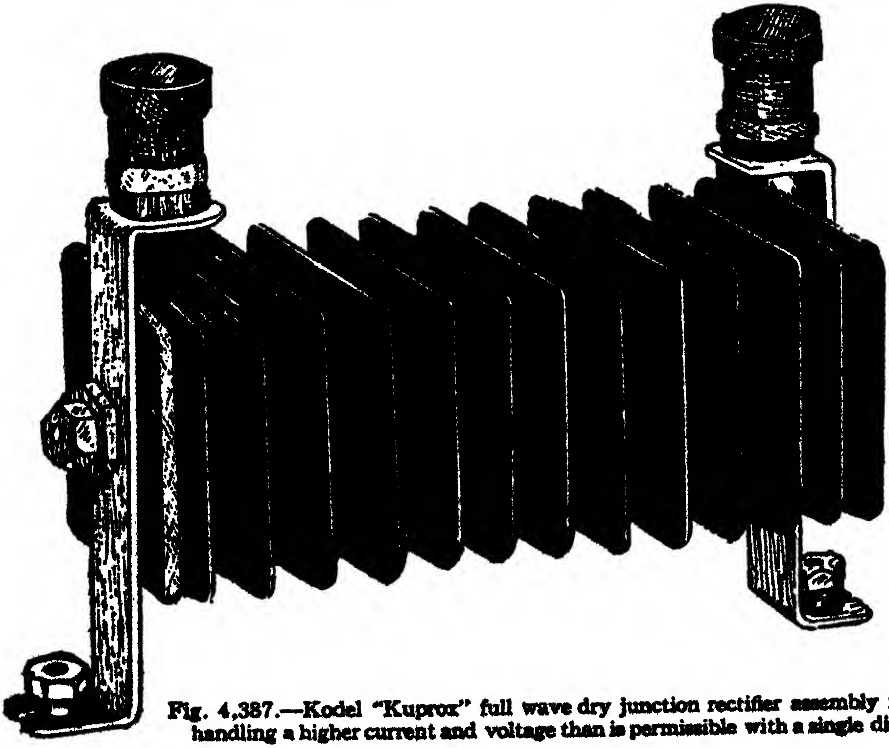


FIG. 4,387.—Kodel "Kuprox" full wave dry junction rectifier assembly for handling a higher current and voltage than is permissible with a single disc.

Fig. 4,390 shows an assembly of four copper oxide rectifier elements into a group for full wave rectification, the connections being the same as in fig. 4,389. Such an assembly may be used without a central tap in the transformer. With good ventilation, such a unit will supply a uni-directional pressure of 6 volts and a current which depends on the area used.

The current density that may be used depends on the effectiveness of the ventilation that is provided. In order to dispose of the power lost in

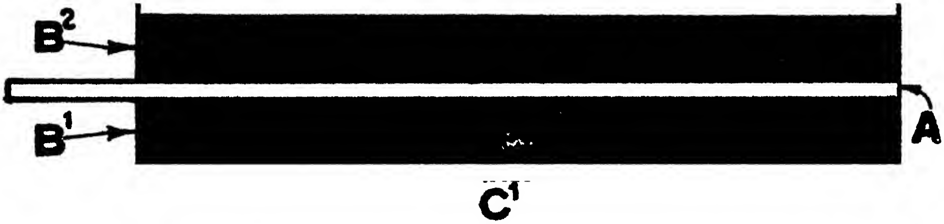


FIG. 4,388.—Kodel "Kuprox" rectifier disc. *The rectification* is due to a thin layer of copper oxide B^1-B^2, formed directly upon a sheet of pure copper A, and coated on its outer surface with a thin copper film C^1, C^2. The direction of current flow, is from the copper films C^1, or C^2, through the intervening oxide layers B^1, or B^2, to the underlying copper plate A. If the positive terminal of a battery or other source of energy be connected to A, and provided the critical voltage be not exceeded, no current will pass through the Kuprox disc upon completion of the exterior surface.

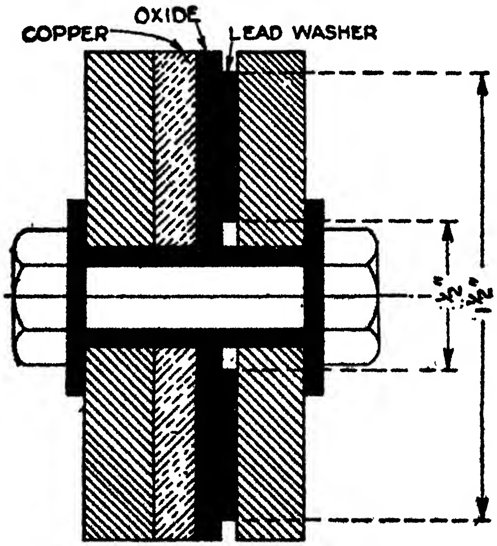


FIG. 4,389.—Assembly of single half wave rectifier.

the rectifier, it may be provided with ventilating fins. With current densities greater than two amperes per square inch, a forced air draught or immersion in oil is necessary.

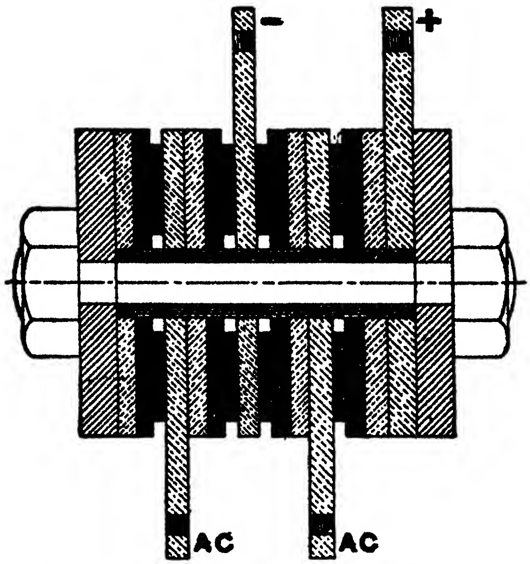


FIG. 4,390.—Group assembly of dry junction rectifier discs for full wave rectification.

TEST QUESTIONS

1. *What is the purpose of a rectifier?*
2. *Give the definition of a rectifier.*
3. *For what applications are rectifiers used to advantage?*
4. *Give a classification of rectifiers.*
5. *What is a mechanical rectifier?*
6. *Of what does an electro-magnetic rectifier consist?*
7. *Name two kinds of electro-magnetic rectifiers.*
8. *What is an electrolytic rectifier?*
9. *What are electrolytic rectifiers sometimes called?*

10. *What metal is extensively used in the construction of electrolytic rectifiers?*
11. *Describe the Nodon valve.*
12. *Describe the Fleming oscillation valve.*
13. *Describe the Grisson valve.*
14. *Who invented the audion valve?*
15. *How does the Churcher valve operate?*
16. *Describe the Pawlowski valve.*
17. *What type is the Buttner valve?*
18. *What significance have the terms* vapor *and* arc *as applied to rectifiers?*
19. *Describe at length the Cooper-Hewitt mercury vapor rectifier.*
20. *What are the two kinds of losses in the rectifier tube?*
21. *What is a mercury arc power rectifier?*
22. *Describe a mercury arc rectifier outfit.*
23. *How is a mercury arc rectifier started?*
24. *Describe at length the American Brown Boveri mercury arc power rectifier.*
25. *Describe the construction of the mercury seal for power rectifiers.*
26. *How does the two stage pump used with the power rectifier work?*
27. *What is the range of sizes of mercury arc power rectifiers?*
28. *Describe the argon gas bulb rectifier.*
29. *Give some points on argon gas.*
30. *Give a number of bulb rectifier troubles, with their remedies.*
31. *What is a dry junction rectifier?*

CHAPTER 81

Lightning Arresters

By definition a lightning arrester is a device *for providing a path by which lightning disturbances or other static discharges are passed to the earth.*

A lightning arrester is a device intended primarily to prevent damage to electrical apparatus which may be caused by disturbances due to lightning. The study of the effects of lightning is of even greater importance than that of the lightning itself.

Most of the effects of lightning found on electrical circuits are due not to a direct stroke of lightning striking the transmission line, but rather due to the so called induced voltage which appears on the transmission line when a cloud over the line suddenly discharges either to ground or to another cloud.

Lightning arresters are not intended to take care of direct strokes, and like poles, or insulators, or other portions of the structure of electrical circuits, may be destroyed by such a discharge.

The magnitude of the voltage which appears on a line when the cloud overhead discharges depends upon the height of the line above the ground and the pressure gradient at the time of discharge in the region where the line is located.

The rapidity with which the voltage appears on the transmission line is determined by the rapidity with which the cloud discharges. As is well known, from watching lightning during a thunder storm, the discharge takes place in a very short time. That time may be, perhaps, the time it takes electricity to travel from the cloud to the ground, which if the cloud be half a mile above the earth and discharged to the earth, would be of the order of 1/400,000 part of a second.

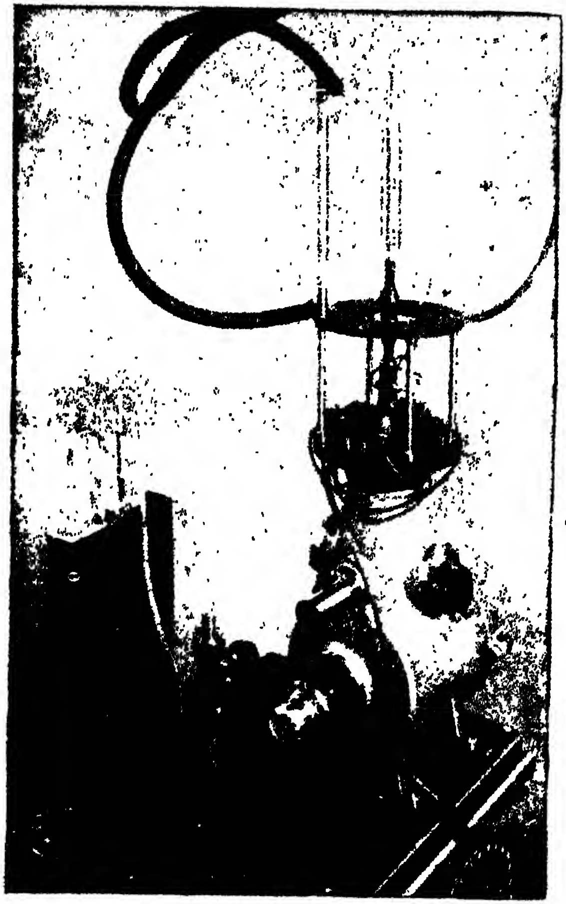
Some observers believe that the lightning discharge is oscillatory in character, while others are of the opinion that the discharge is unidirectional.

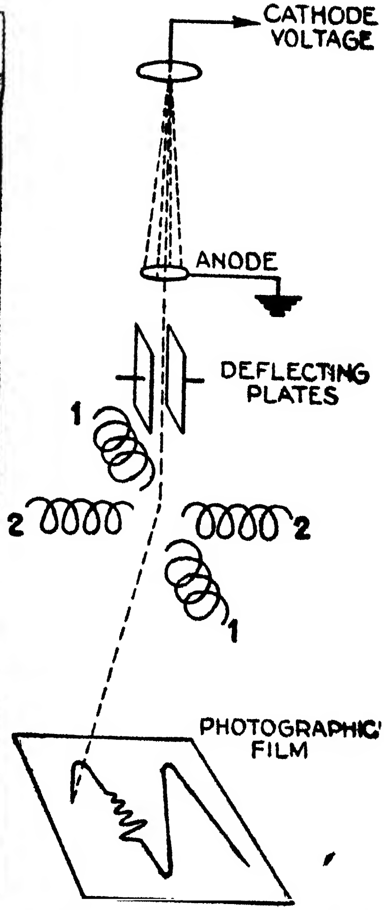
Considerable material has been written concerning the magnitude of the voltage and current which may be found in lightning discharges. Valuable as these factors are in helping to clear up the lightning problem, the magnitude of the voltage on the line and the rate at which it builds up are of immediate importance.

Since the portion of the line under the cloud is charged to a certain voltage against ground, the transmission circuit so affected may be considered as a condenser which discharges into the rest of the circuit not under the cloud. As a result of such a discharge, two waves of voltage travel along the transmission line in opposite directions from the disturbance. If these waves do not flash over some insulator as they travel along the line, they will continue until some inductive electrical apparatus is reached where insulation between turns or between conductors and ground may be punctured or otherwise damaged unless properly protected by a lightning arrester. Any study, then, of the lightning problem must involve the study of the effects of a wave traveling along an electrical conductor, these waves being so constituted that the voltage rises from zero to a maximum of many times the operating voltage of the line in a period of time as short as a few microseconds.

Considerable experimentation has been made with discharges of condensers producing waves of this character, but no means have been available whereby the exact form of these waves could be determined, until recently.

A scientific study of the whole problem involves the use of some oscillo graphic device such as shown in figs. 4,391 and 4,392, which will depict easily and accurately transient phenomena of extremely short duration.





FIGS. 4,391 and 4,392.—Dufour oscillograph. Fig. 4,391, external view, fig. 4,392, elementary diagram showing operation. There are two sets of deflector coils 1, 2, 3, 4, so arranged as to produce a time scale which may give a distance of several *cm.* on the film corresponding to a millionth of a second. In one of the sets of deflecting coils a transient current is passed in such a manner that the electron stream is held off the film until the proper time arrives, when it sweeps across the film at a uniform rate. The circuit is so arranged that the electron stream does not again return to the film. Thus, with these so called sweeping coils only in use, a straight line is traced. Through the other set of deflecting coils is passed a current from an oscillator whose amplitude is adjusted so that the electron stream is not deflected beyond the edges of the film. When these coils only are energized a straight line is traced. When both of these coils are energized simultaneously the effect is to produce a wave form. By these means a time scale is produced in either of two directions as desired. By using the sweeping alone without the oscillator, a time scale may be obtained such that 1 in. along the film is equal to about 8 microseconds. Using the oscillator alone the magnification of the time scale is limited only by the frequency which it is possible to secure in the oscillator circuit.

Terms Relating to Arresters

For a clear understanding of this chapter the reader should note the following:

Definitions

Cathode Ray Oscillograph.—A cathode ray oscillograph is an instrument in which the moving parts consist of cathode rays. This has a very high speed and can be used to accurately record surges of very short duration.

Characteristic Element.—The characteristic element of a lighting arrester is that part of the arrester which controls the discharge current and which suppresses the follow current.

Discharge Current.—The discharge current of a lightning arrester is the current resulting from the surge which flows through the lightning arrester to earth during the time the lighting surge is taking place on the circuit.

Follow Current.—After the surge current caused by the lightning disturbance, passes through the lightning arrester, there is formed a conducting path through which the normal or generated current of the circuit may also flow. Although this generated current is finally stopped, some of the current follows the surge current through the lightning arrester and this current is called *follow current.*

Ground.—Any conducting connection between an electrical circuit and the earth, is called a *ground* or *earth,* the word earth being more accurate when applied in connection with the use of lightning arresters.

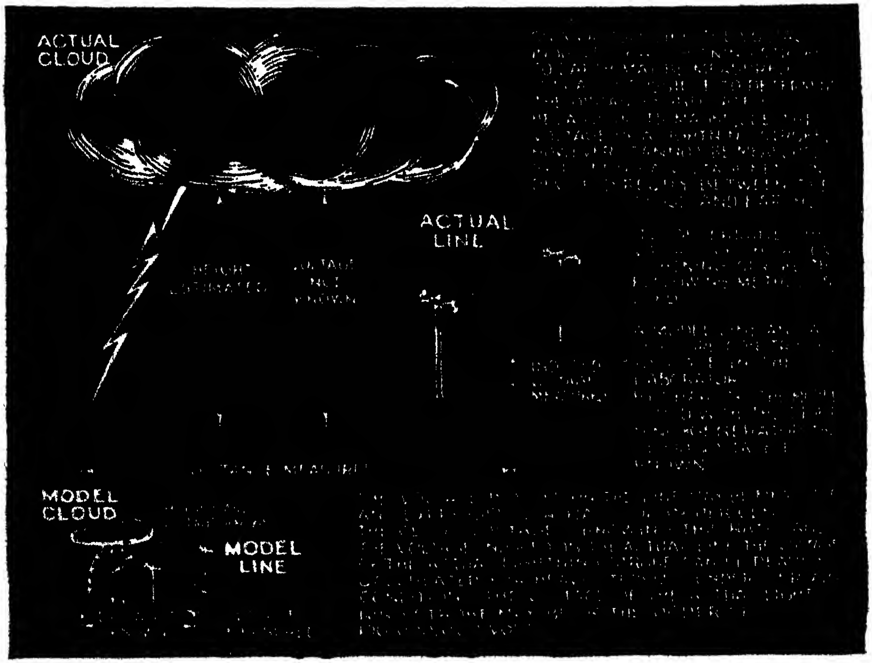
Horn Gap.—A horn gap is a spark gap equipped with metal horns to assist in interrupting the follow current. Such a gap is sometimes used as a series gap with a lightning arrester.

Lightning.—Lightning is an electrical discharge occurring in the atmosphere from cloud to cloud, between cloud and earth or within a cloud. When such a discharge between cloud and earth terminates on a transmission line, a distribution line, electrical machinery or other objects, it is called a direct stroke of lightning. Although direct strokes may be destructive, they usually strike electrical systems only in the transmission

circuit, where, at the present state of the art, it is not economic to completely protect against them. Lightning arresters are not in general designed to protect against direct strokes.

Lightning Arrester.—A lightning arrester is a device providing a path for electric current between any electric circuit and the earth, through which, upon occurrence of a lightning surge, current will be conducted in sufficient amount to reduce the over voltage of the circuit caused by the surge, and after this reduction, the current will cease to be so conducted.

Lightning Surge.—A lightning surge is a temporary electrical disturbance in an electric circuit caused by lightning.



Figs. 4,393 and 4,394.—Method of measuring the voltage of an actual lightning stroke.

Protected Series Gap.—A protected series gap is a series gap protected from rain and other precipitation by a roof or cover.

Series Gap.—A spark gap connected in series with a lightning arrester which keeps the circuit through the lighting arrester open under normal conditions, but closes the circuit for the lightning discharge by sparking over.

Classification.—Lightning arresters may be classified

1. With respect to their use, as to

a. The kind of circuit to be protected: such as power or communication circuit.

b. Location: that is, whether it be for use on distribution circuits or at large stations.

c. Weather protection; whether indoor or outdoor type.

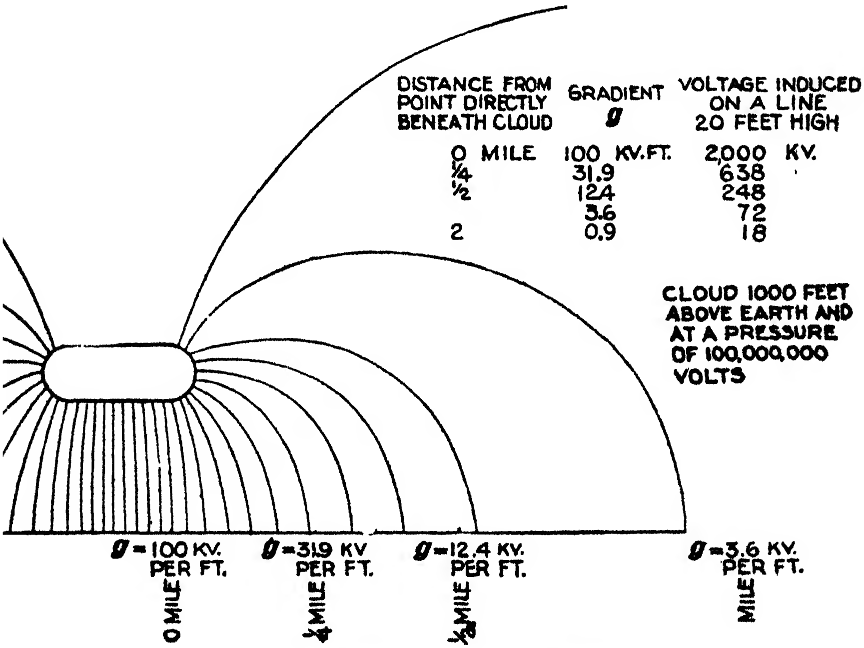


FIG. 4,395.—Electric field voltages in space caused by charged cloud.

d. Nature of generated current; whether *d.c.* or *a.c.*

e. The system of connection; whether it be earthed or non-earthed.

2. With respect to control of follow current, as

a. Valve type.

b. Follow current type.

Ques. What are the causes of static charges?

Ans. They may be caused by sand storms in dry climates, charges from overhead clouds, smoke, dust particles in the air, etc.

Ques. What causes high frequency oscillations?

Ans. They are usually due to lightning discharges in the vicinity of the line, either from cloud to cloud, from cloud to earth, or within a cloud.

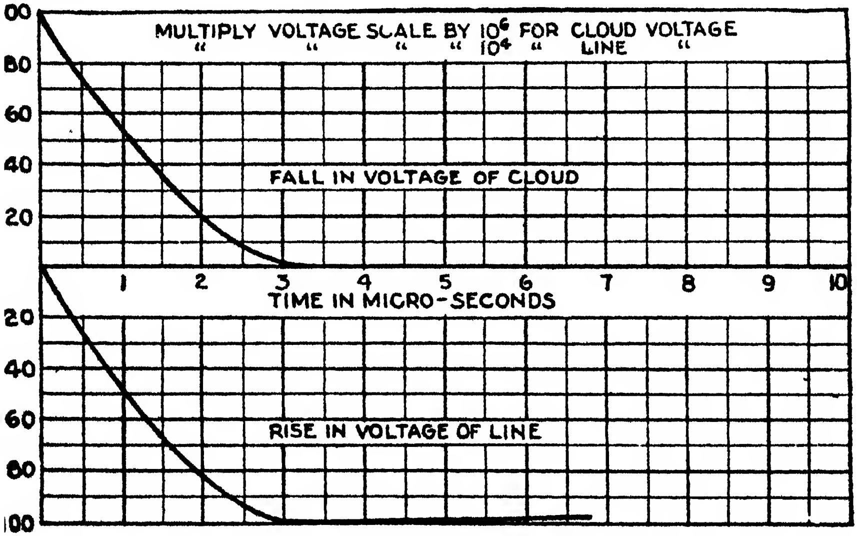


FIG. 4,396.—Curves showing the manner in which the voltage increases on the line with decrease in voltage on the cloud.

Ques. What are the requirements of lightning protection devices?

Ans. They must prevent excessive pressure differences between line and ground, line and line, and prevent damage to electrical machinery by keeping the pressure, due to lightning, at a low value.

Ques. What is a spark?

Ans. The conduction of electricity by air.

Ques. What is an arc?

FIG. 4,397.—Lightning discharge from transmission line photographed on revolving film tests made in the mountains of Colorado. A 24 mile idle line was available. The lightning was permitted to discharge to ground through a large gap in series with a small auxiliary gap in a dark box. A rapidly revolving photographic film on a steel disc recorded the discharge. Many of these discharges were photographed. In all cases, following the first impulse, a very highly damped oscillation took place at the natural period of the line or about 1,900 cycles.

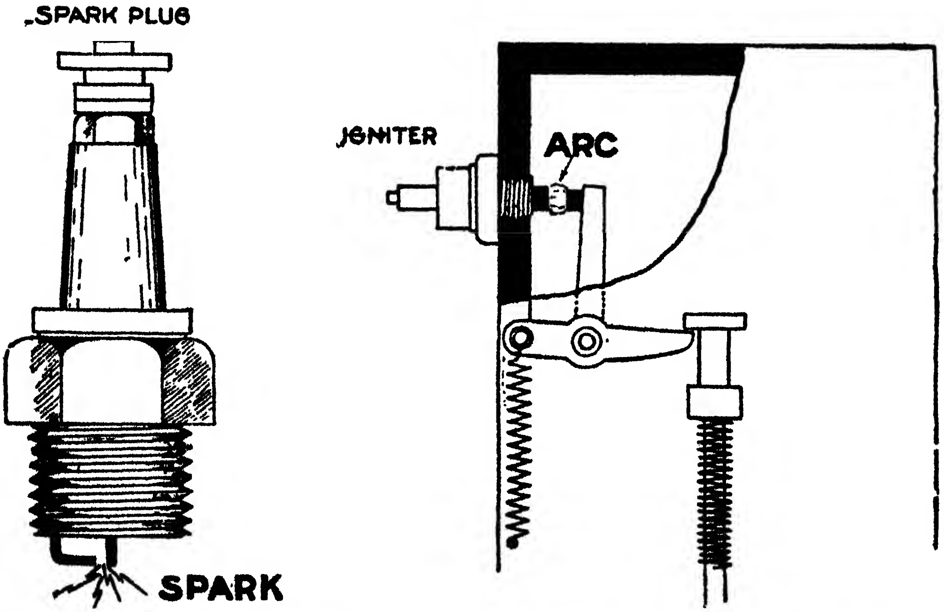
Ans. The conduction of electricity by vapor from the electrodes.

Ques. What is the difference between an arrester for a grounded Y and non-grounded neutral system?

Ans. The difference in design is that the arrester for the non-grounded neutral system must be built to take care of a higher

voltage. The reason for this is that under certain conditions the non-grounded system has a higher voltage to ground than the grounded system and this requires a higher voltage lightning arrester.

Ques. Why is a higher voltage obtainable with the non-grounded system?



FIGS. 4,398 and 4,399.—Two familiar illustrations showing the distinction between a spark and an arc.

Ans. If one line become accidentally grounded, the full line voltage would be thrown across one leg. On a Y system with a grounded neutral, the accidentally grounded phase causes a short circuit of the phase and the arrester is relieved of the strain by the tripping of the circuit breaker. Briefly stated, a higher voltage arrester is used when for any reason, the system can be operated, even for a short time with one phase grounded.

Valve Type Arrester.—This type arrester is one *whose characteristic element has a very high resistance at normal voltage, which resistance decreases as the voltage increases and then returns to its normal value when the surge voltage returns to zero.* These characteristics result in suppressing the follow current.

In other words, the valve type acts as a valve and lets the high pressure surges pass through the arrester, but shuts the valve when the normal line current attempts to follow.

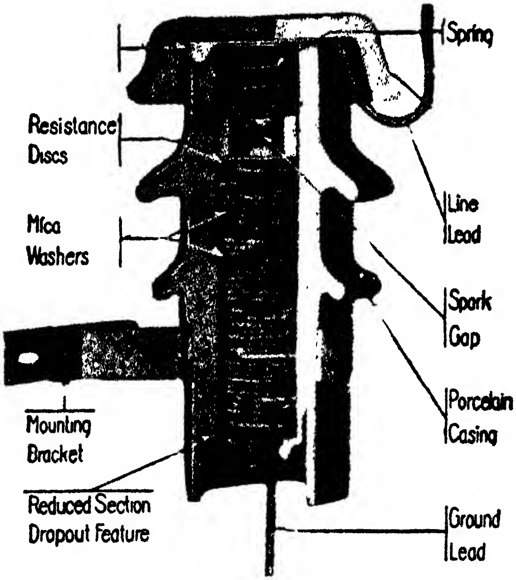


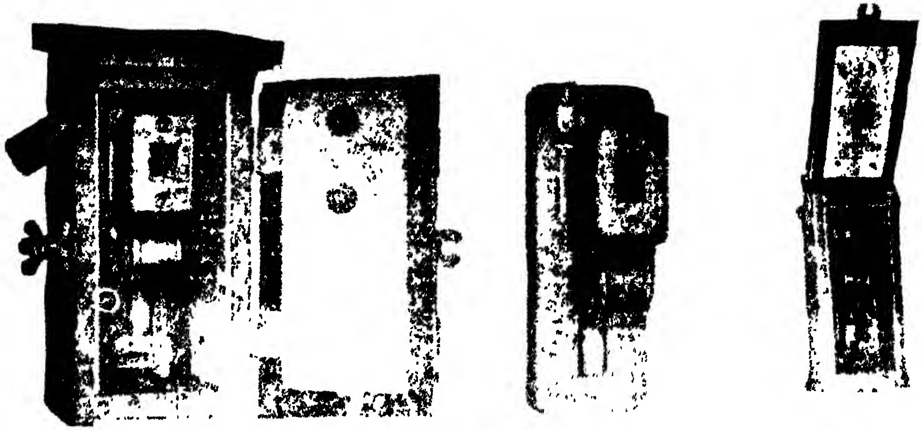
Fig. 4,400.—Westinghouse valve type arrester for protection of distribution transformers; voltages up to 50,000. The protection of distribution systems is mainly a problem of distribution transformer protection. This differs in every respect from the problem involved in the protection of station type apparatus. *The construction* of the arrester is plainly shown in the illustration.

Follow Type Arresters.—By definition a follow current type arrester is *one that permits follow current to flow and then puts out the follow current.*

This method of putting out the follow current might be by means of

a magnetic blowout; the change in characteristics of metal vapor preventing the reversal of current; or allowing the heat of an arc to draw it out and break it as in the horn gap type.

Protective Characteristics.—The protective ability of a lightning arrester depends upon *the voltage to which it allows the surge to go and the time during which it permits such voltage to be maintained.*



FIGS. 4,401 to 4,403.—General Electric magnetic blowout (follow type) arresters. Fig. 4,401 for outdoor service up to 750 volts; fig. 4,402 for indoor 750 volt service; fig. 4,403 type for mounting under car, 350-750 volts.

Although the time of a lightning surge is very small, and can only be measured in millionths of a second, this time is important, and the length of time that the high voltage is impressed on the electrical machinery, in addition to how high the voltage is, determines whether the electrical machinery will have a breakdown of its insulation or not.

Air Gap Arresters.—A method of relieving any abnormal pressure condition is *to connect a discharge air gap between some point on an electric conductor and the ground.* The resistance thus interposed between the ground and the conductor is such that any voltage very much in excess of the maximum normal will cause a discharge to ground, whereas at other times the

conductor is ungrounded because of the air gap. This forms the principle of air gap arresters.

The single gap, while adequate for telegraph line protection, was found insufficient for electric light and power circuits, because since the current of such circuits is considerable and usually at high pressure, it would follow the lightning discharge across the gap. Thus the problem arose to provide means for preventing the line current going through the arrester, and this has resulted in the introduction of several new forms

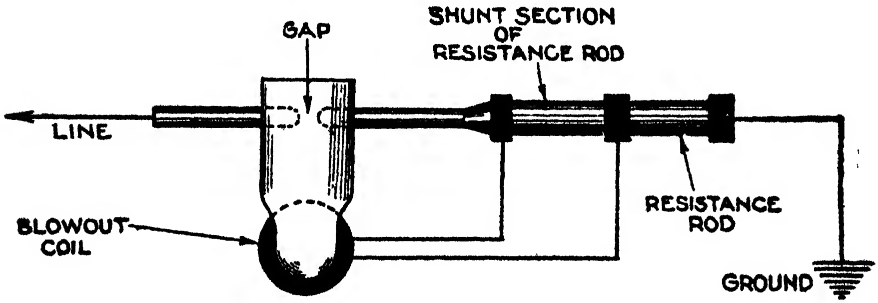


FIG. 4,404.—Diagram illustrating operation of magnetic blowout (follow type) arrester. The arrester *consists* of an adjustable spark gap in series with a resistance. Part of the resistance is in shunt with a blowout coil, between the poles of which is the spark gap. The parts are mounted on a porcelain base which, for outdoor service, is in turn mounted in an asbestos lined wooden box. *In operation*, when the lightning voltage comes on the line, it causes the spark gap to break down and a discharge occurs through the gap and the resistance rod to ground. Part of the line current following the discharge shunts through the blowout coil, producing a strong magnetic field across the spark gap. The magnetic field blows out the discharge arc and restores normal conditions.

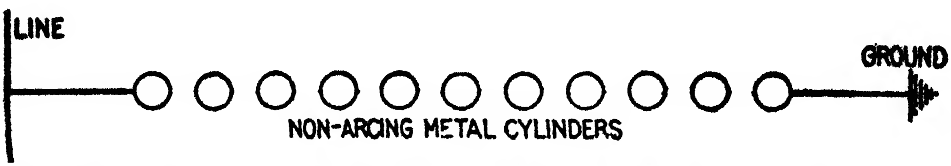


FIG. 4,405.—Non-arcing multi-gap arrester. Based on the principle of employing for the terminals across which the arc is formed, such metals as are least capable of maintaining an alternating arc between them. This so called non-arcing property of certain metals was discovered by Alexander Wurtz. The action is such that the "line current" which follows the lightning discharge follows as an arc, but is stopped at the end of one alternation because of the property of the non-arcing metals to carry an arc in one direction, but requiring an extremely high voltage to start a reverse arc. The non-arcing metals ordinarily employed are alloys of zinc and copper. Plain multi-gap arresters as here shown operate satisfactorily with the smaller machines and on circuits of limited power, particularly low voltage circuits.

of arresters, particularly the pellet type and the station type oxide film lightning arresters.

Operation of a Lightning Arrester.—The cycle by which a lightning arrester operates includes the following action:

1. Due to the series gaps, no current from the line passes through the arrester and the arrester circuit stays open;

2. When the lightning surge takes place, the voltage goes up high enough to arc over the series gap, and the surge current or discharge passes through the lightning arrester to earth;

3. The surge current continues to flow as long as the surge voltage is on the line, and after this stops flowing, a small amount of the generated current on the line may flow also, depending upon the type of arrester;

4. As soon as the surge voltage has been reduced to a very low value, the surge current stops flowing, and shortly after, the follow current, if any, stops flowing and the arrester is restored to the original condition.

As soon as the arrester has discharged as just described, it should be ready for another discharge in case of other lightning voltages.

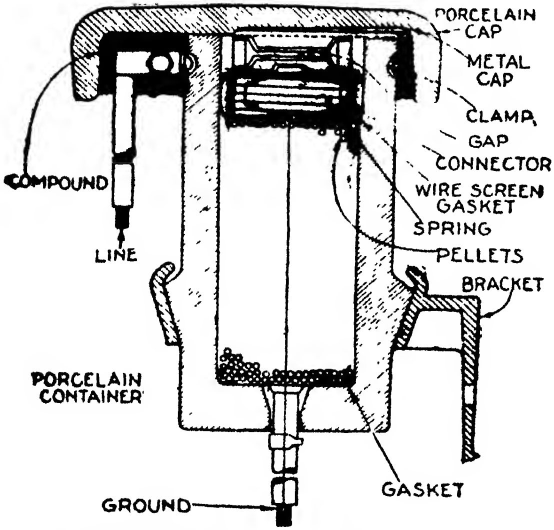
Pellet Arresters.—The essential elements of an arrester of this type are *a number of small pills about 3/32 in., in diameter made of lead peroxide.*

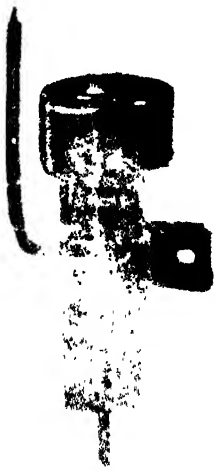
These are coated with litharge powder which forms a film around the pill. These litharge coated pills or pellets are placed in a porcelain tube and assembled in good electrical contacts with metal electrodes at each end of the column.

Between the line lead and the pellet column is one or more series gaps which separate the pellets from the line under normal conditions, but which allow a discharge to take place, when

the voltage reaches a sufficiently high value above normal voltage.

This construction is shown in figs. 4,406 and 4,407. The finished arrester as here shown consists of hundreds of miniature cells in series and in parallel. The litharge film apparently acts as a porous spacer and not as a solid insulation. This gives high speed and freedom of discharge.





FIGS. 4,406 and 4,407.—General Electric pellet type arrester. *Application:* The pellet oxide film arrester is made for application to *a.c.* constant pressure circuits of voltages up to 50,000. It is for outdoor service only and is used primarily for the protection of distribution transformers and moderate sized substation transformers. The pellet type of oxide film arrester is a modification of the well known cell type of oxide film arrester. The latter type, which was developed for large stations and large outdoor transformers, has been in successful service since 1915 on circuits with voltages ranging from 300 to 220,000. This arrester is of the valve type.

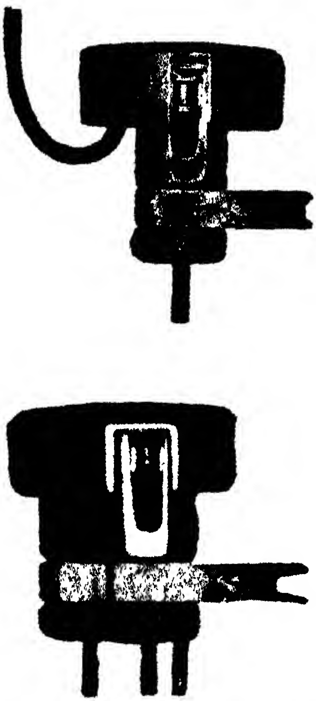
High voltage surges go through this pellet arrester in a number of parallel paths and the sealing occurs at the contact surfaces of all the pellets in the path of the surge current.

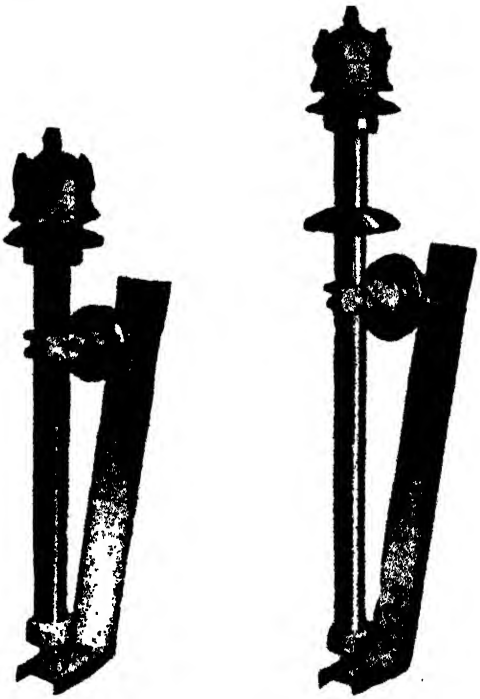
It might be expected that such small contact surfaces as exist between the pellets would be quickly worn away by the discharges, but this is not the case. The contact surface is punctured by the discharge, but the

sealing at once reforms the film and the contact surface is restored, ready for additional service.

The pellets have the mechanical strength to withstand the heavy surges that this type of arrester will discharge.

The satisfactory performance of this arrester, or any lightning arrester, depends upon its application to circuits where the maximum voltage at no time exceeds the maximum rating of the arrester.





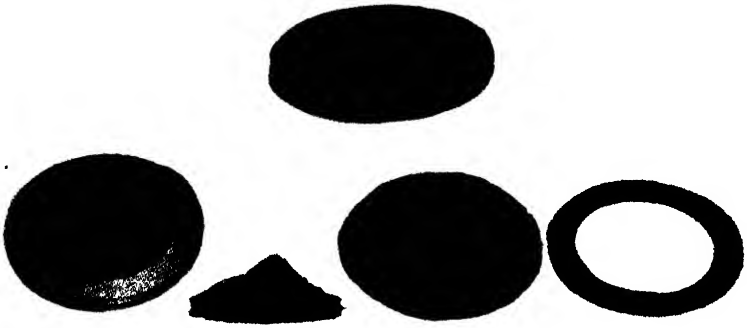
Figs. 4,408 and 4,409.—General Electric compression chamber arresters; sectional views show compression chamber.

Figs. 4,410 and 4,411.—General Electric pellet type oxide film arresters. Fig. 4,410, 25,000 volt; fig. 4,411 37,000 volt.

Compression Chamber Arresters.—These are made for the protection of apparatus on secondary lighting and power circuits. The 750 volt arresters are especially suitable for the protection of apparatus on railway signal feeder circuits. All are for outdoor service only.

The essential elements of a compression chamber arrester are *two electrodes with a small air gap between them, placed between line and ground.* The lightning voltage sparks over the gap and a current flows to ground, thus relieving the lightning strain.

The gap electrodes are made of a brass alloy, which gives off a zinc vapor due to the heating of the current. This vapor has a rectifying effect preventing the reversal of the current, so that at the end of the cycle on which the discharge occurs, the line current following the discharge is



FIGS. 4,412 to 4,416.—General Electric oxide film arrester cell. Fig. 4,412, figs. 4,413 to 4,416, cell before assembly. *In construction* the cells are held together under moderate pressure and are arranged in sections or stacks according to the voltage and kind of circuit. The cells are disc shaped, about 7½ ins. in diameter and ½ in thick as shown. The active area is approximately 23 sq. in. Each cell is made of two circular brass plates crimped firmly to the edges of an annular piece of porcelain, as shown in fig. 4,416. A powder, lead peroxide, which has very low resistance, compactly fills the space between the plates. The inside of the metal plates is covered with a varnish film which is an insulator. The number of cells used in an arrester is such that the voltage per cell is approximately 300 volts. The active area is about 23 sq. in.

cut off and normal conditions are thus restored. In the compression chamber arrester the gap electrodes are separated by a porcelain spacer. It will be noted in figs. 4,408 and 4,409 that the brass alloy makes a small closed chamber.

During the discharge, *the gases formed by the arc are held within these chambers and become slightly compressed and assist in extinguishing the arc by partially smothering it.* This feature gives the arrester its name.

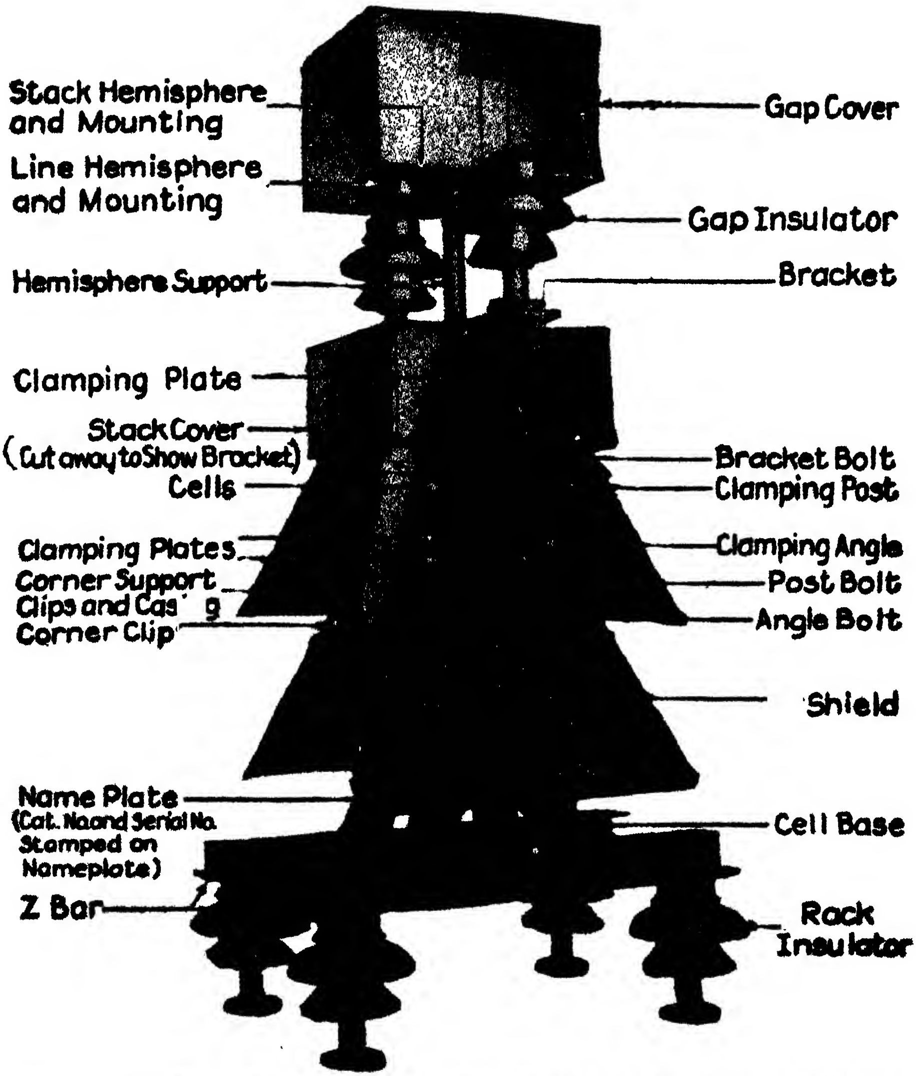


FIG. 4,417.—General Electric oxide film arrester; sectional view showing construction and names of parts. In putting in the cells, they are stacked up and clamped between treated wooden supports. The clamping construction is such that cells can be removed from one section without disturbing those in another. Arresters for outdoor service have galvanized sheet iron louvres attached to the wooden supports to give protection against the weather. These louvres can easily be removed for inspection and repairs.

Oxide Film Arresters.—This type arrester consists essentially of *a number of cells with a gap in series between line and ground.*

The cells are held together under moderate pressure and are arranged in sections or stacks, according to the voltage and kind of circuit. The cells are disc shape, about 7½ in. in diameter and ⅝ in. thick as shown in fig. 4,412.

In operation when a lightning voltage sparks over the gap, *it is impressed on the cells and breaks down the insulating coating on the metal plates.*

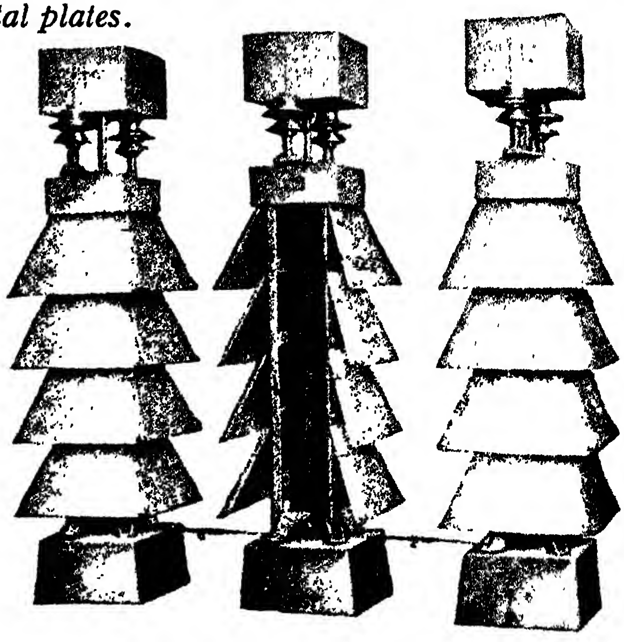
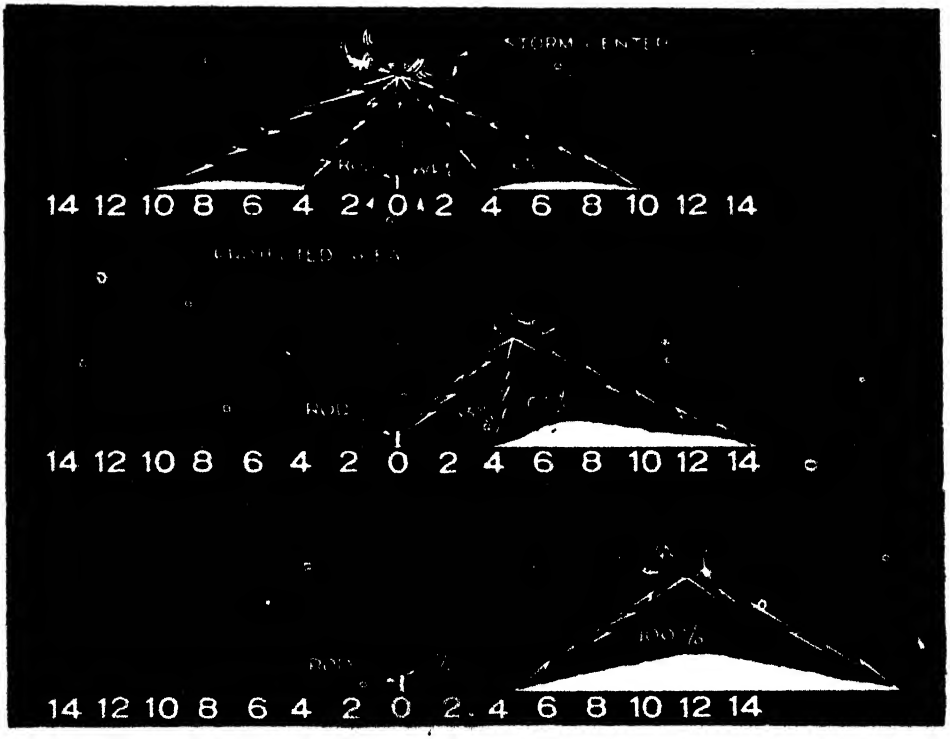


FIG. 4,418.—General Electric three phase oxide film arrester for outdoor service 20,000 to 25,000 volts; shields of middle leg removed for inspection.

A breakdown occurs in the form of a minute crater on the film coating. The metal plates are not punctured. As soon as the crater forms, a discharge current flows through the cells to ground thus relieving the lightning pressure. The flow of current through the cells, through some action, the theory of which at the present time is not entirely understood, seals up the opening to the crater and prevents the generator current following

the lightning discharge. The arc in the series gap dies out and the arrester is again disconnected from the line.

If the voltage should still or again be sufficiently high to break down the gap, the operation is repeated, either at the same point or some other point on the surface of the varnished plates. These operations may continue for many years, the sealing action taking place over the entire area and sometimes in the same identical point that the previous discharge took place.



FIGS. 4,419 to 4,421.—Protected area and distribution of hits between rod and ground for different positions of storm center.

When arresters of this type are used an inspection should always be made at the beginning and end of each lightning season.

If the cells be found mechanically intact, the arrester can be considered in first class operating condition.

The number of cells required for a given operating voltage is determined by allowing about 300 volts per cell.

It is possible to pre-determine the characteristics of an oxide film lightning arrester in a laboratory by using a lightning generator and a cathode ray oscillograph.

Ques. Can oxide film lightning arresters be operated at a low voltage temporarily and later at a high voltage?

Ans. Yes.

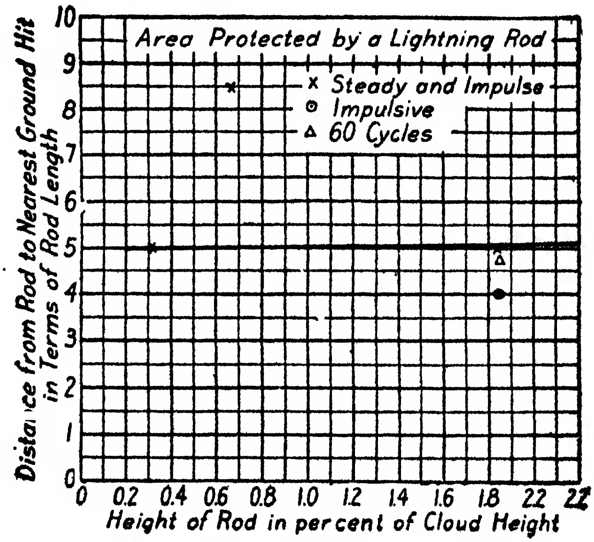


FIG. 4,422.—Area protected by a lightning rod.

This can be done by putting in enough cells for the final voltage, and short circuiting the extra cells while operating at the lower voltage.

Ques. Describe the operations necessary in putting oxide film arresters in commission.

Ans. The arrester should be assembled in accordance with construction drawings and the hemisphere gap adjusted for the correct gap setting.

All grass, weeds, and other obstructions should be removed from under or near the arrester, as these are liable to short circuit the live parts. The insulators, hemispheres and other parts should be thoroughly cleaned with a dry cloth to remove dust, surplus compound, etc.

The arresters should have an initial charging operation and after that they should be charged at the beginning of each lightning season. When possible, it is advisable to reduce the line voltage to half voltage and raise it in steps of three quarters in full voltage, charging the arrester at each step.

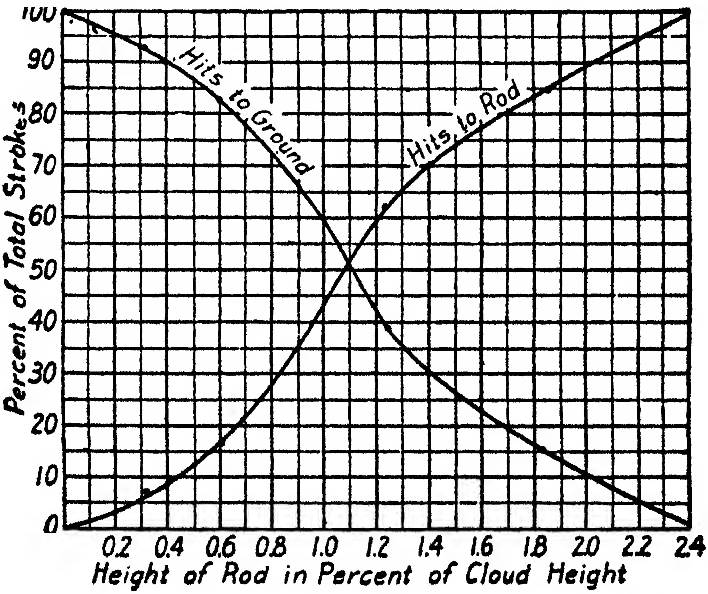


FIG. 4,423.—Division of hits between rod and ground for different heights of rod. When the rod has zero length, 100% of the hits must strike the ground. When the height of the rod is 1.1% of the cloud height, the division of hits is equal, while all of the strokes go to the rod when it is about 2.5% of the cloud height. Over this range, the ground was never hit nearer to the rod than four times its height.—*General Electric tests.*

The procedure in any case will be as follows:

1. Disconnect the arrester from the line.

2. Discharge each stack of the arrester to ground.

3. Inspect all connections and mechanical parts to ascertain if all be in good condition.

4. Where the line voltage is reduced for charging, all three gaps can be shorted at the same time with not greater than a 5 ampere fuse wire across eacn gap. Where the line voltage cannot be reduced, it is advisable to short each gap in turn before finally shorting all three gaps. At each voltage gap the voltage should not be held over three minutes. If the fuses blow, or the cells show signs of trouble, indicated by any compounds being blown out, the operation should be discontinued and the arrester disconnected, as the line circuit or arrester connections may be at fault.

5. After the arrester has been satisfactorily charged, disconnect the arrester from the line and discharge the cell stack to ground. To discharge cell stack to ground, it is not necessary to discharge each individual cell. After the arrester is disconnected from the line, the line side of the gap should be grounded. Short circuiting the gap with the arrester disconnected from the line will then discharge the cell stacks to ground.

6. Remove all short circuit connections and inspect all parts to see that all mechanical parts are making proper contact.

7. Make sure that the gaps are set in accordance with the gap settings applying to the particular altitude that they are being operated at, and put the arrester in service.

Ques. When is the pellet type of arrester used and when is the oxide film type of arrester used?

Ans. The pellet type of arrester is generally used to protect small circuits, small banks of transformers, and other electrical machinery where the cost will not warrant the larger and more expensive arrester. The oxide film lightning arrester is used for all important stations for protecting large banks of transformers, and for protecting circuits where trouble from lightning would be very dangerous and expensive.

Ques. What are the essentials for giving satisfactory lightning protection to electrical machinery?

Ans. They are as follows:

1. A lightning arrester should be selected that will impress the lowest voltage, for the shortest time on the insulation during lightning disturbances.

2. The lightning arresters should be placed as close to the electric machinery it is protecting as possible. If it be placed too far away, the arrester will be unable to protect, or will give less protection than it would if it were right adjacent to the apparatus it is protecting.

3. The ground resistance must be as low as possible. No arrester can be effective with a high ground resistance.

4. The arrester should be selected for the proper voltage so that the rating of the arrester will not be exceeded under normal conditions due to regulation of the circuit, the use of induction regulators, delay in circuit breaker opening, etc.

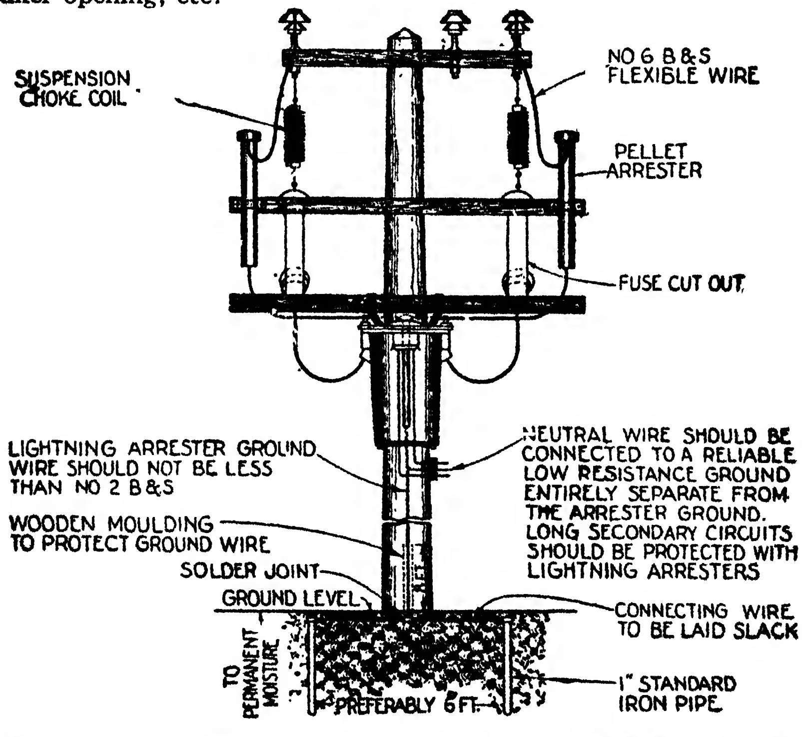


Fig. 4,424.—Method of grounding for pole type lightning arresters protecting distribution transformers. Under average soil conditions this method should provide a resistance of 15 ohms or less, which if maintained, will be adequate for the pole type arresters. A single driven pipe, if liberally salted, will frequently give a suitably low resistance value for arresters on the customary 2300-4000 volt class of distribution circuits, particularly in regions of large arrester density. A ground resistance much above 15 ohms becomes questionable particularly in sections where the transformer density is a minimum; that is, where the number of discharge paths in parallel would be a minimum, thus requiring the total energy induced on the circuit over a considerable area or length of line to be discharged through but one or two arrester installations. In other words, the minimum ground resistance is desirable in areas of minimum installation density.

Ques. What means are available to determine which arrester gives the best protection?

Ans. It is possible, in a laboratory, by means of a lightning generator and a cathode ray oscillograph, to see the path of the discharge through the lightning arrester, what voltage the lightning arrester allows the circuit voltage to go to, and how long this high voltage is impressed on the insulation of the electrical machinery being protected.

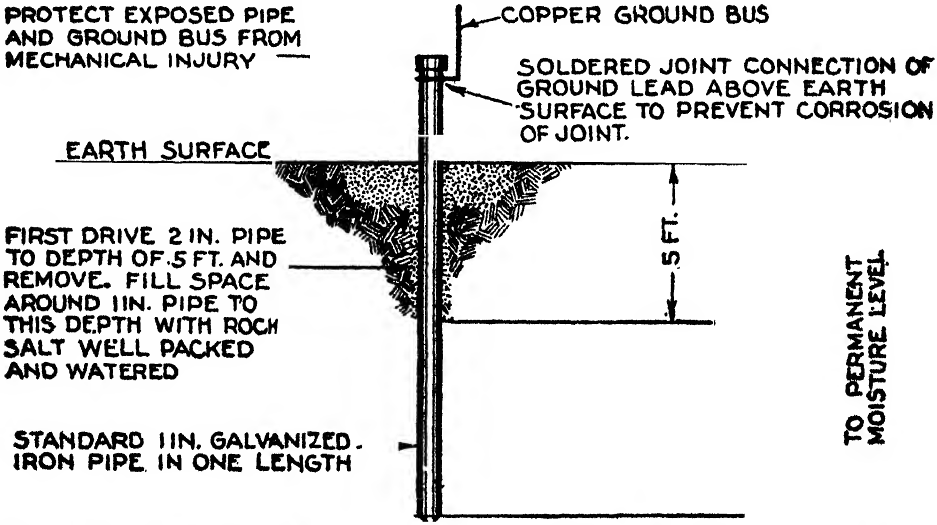


FIG. 4,425.—Pipe ground element. Drive one inch iron pipes to the permanent moisture level and then salt the ground around the pipes to a depth of several feet. The number of arrester grounds depends upon the character of the soil and the size of the arrester installation. For the average power or lighting station, the installation of four such ground pipe arrangements as here described should be sufficient. These should be located near each outside wall of the station and bussed solidly together. One of these groups should be installed at a point nearest the arrester, or a fifth put in at such a point. It is adviseable to connect these earth pipes to the iron framework of the station, and also to any water mains, metal flumes, or trolley rails that are available. In no case should there be less than two pipe grounds installed, and where accurate records are to be kept of ground resistance, at least three such pipe grounds should be made, with the individual pipes six feet or more apart.

Ques. Is this the only requirement for a good arrester?

Ans. No, it is also necessary to have an arrester rugged enough to withstand unusual conditions.

Grounded and Ungrounded Neutral Circuits.—It is important to avoid the mistake of using an arrester for a thoroughly grounded neutral, when the neutral is only partially grounded, that is, grounded through an appreciable resistance. Careful consideration of this condition will make the above statement clear.

In an arrester for a grounded neutral circuit, each leg of the

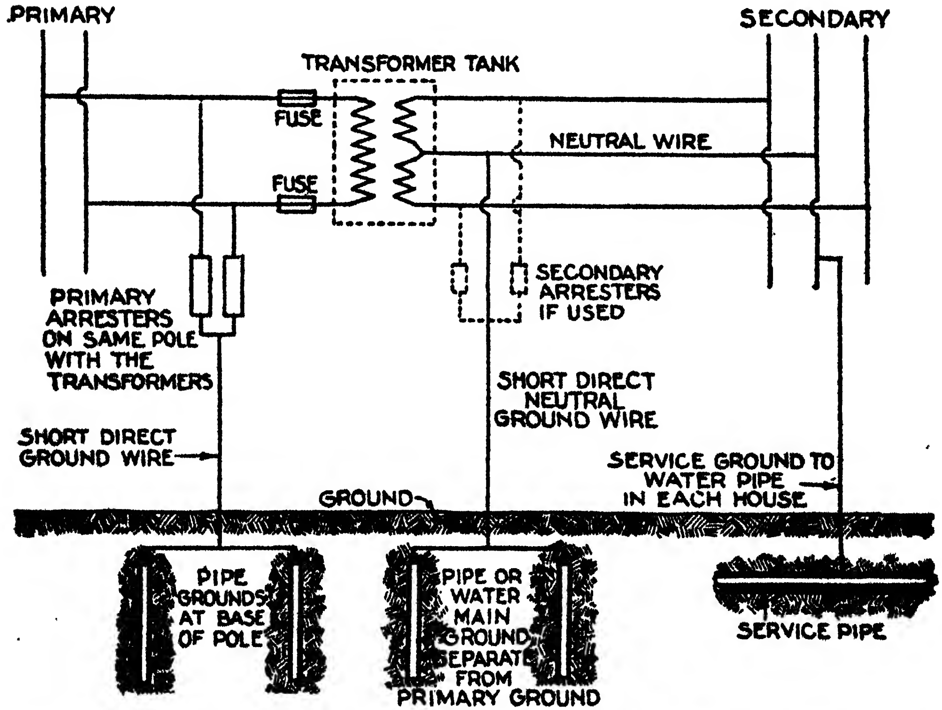
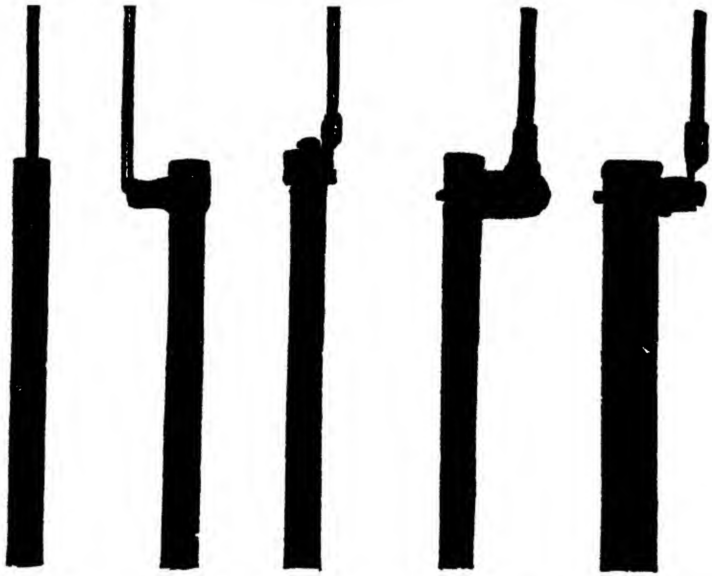


FIG. 4,426.—The system of multiple driven pipes for grounding arresters used to protect transmission line apparatus. The ground pipes are driven close against the arrester foundation, the latter affording mechanical protection against broken connection to pipes. All of the copper connecting bus and actual connections to the pipes are above the surface of the ground, promoting ease of inspection and testing. The number of pipes to be used depends upon the soil texture and resistivity, but under good soil conditions three or four driven pipes well treated with salt will be satisfactory, while in many cases the soil conditions will require eight or ten pipes which may be installed as shown and spaced not less than 6 feet on all sides of the arrester foundation. A good value of resistance for arresters protecting station and substation apparatus will not be over 5 ohms, and in the case of the larger and more important arrester installation even lower values of ground resistance should be attained.

arrester normally receives the neutral pressure when the arrester discharges, but if a phase become accidentally grounded, the line voltage is thrown across each of the other legs until the circuit breaker opens the circuit.

The line voltage is 73% greater than the voltage to neutral or normal operating voltage. This means that when a grounded phase occurs, this 73% over voltage is short circuited through the arrester until the circuit breaker opens.



FIGS. 4,427 to 4,431.—General Electric pipe ground connections.

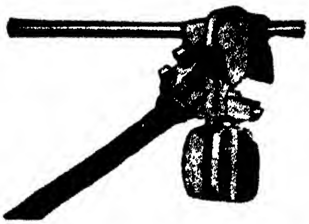
The amount of energy to be dissipated in the arrester depends upon *the kilowatt capacity of the generator, the internal resistance of the arrester and the time required to operate the circuit breaker.*

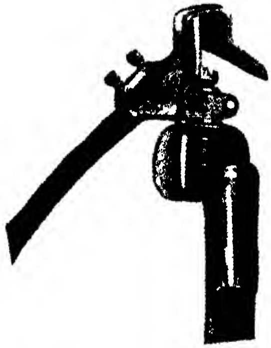
It is evident that the greater the amount of resistance in the neutral, the longer will be the time required for the circuit breaker to operate. Therefore, in cases where the earthing resistance in the neutral is great enough to prevent the automatic circuit breaker opening practically instantaneously, an arrester for a non-grounded neutral system should be installed.

Ground Connections.—In all lightning arrester installations, it is very important to make proper ground connections, as many lightning arrester troubles can be traced to bad grounds.

It was formerly considered best to ground a lightning arrester by means of a large metal plate buried in a bed of charcoal at a depth of 6 to 8 ft. in the earth.

A more satisfactory method of making a ground is to drive a number of 1 in. galvanized iron pipes or copper welded rods down to permanent moisture surrounding the station, connect-



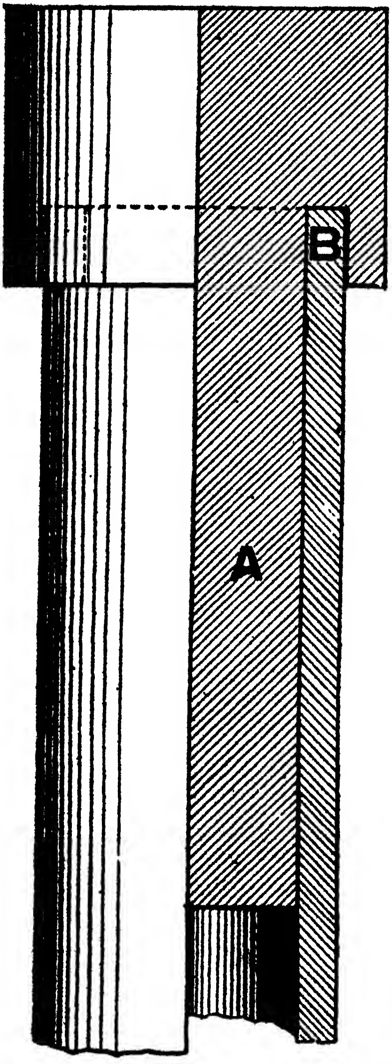


FIGS. 4,432 and 4,433.—General Electric line connectors. Fig. 4,432, attached to line; fig. 4,433, attached to pole. Line connectors are supplied with all lightning arresters above 85,000 volts. These connectors are provided with soldered in cable and also set screws for holding cable in the connector. *To operate,* insert the switch hook in the eye of the connector and turn to left until the connectors then may be placed on the line and released from the switch hook by a right hand screw action. The reverse operation will detach the connector from the line and securely lock it to the switch hook. Attaching connector to arrester frame will then ground line side of gap. Short circuiting the hemisphere gap will discharge the arrester to ground.

ing all these pipes together by means of a heavy copper wire or preferably by a copper strap.

If good grounding conditions be not obtained in this way, a quantity of salt should be placed around each pipe at the surface of the ground and the ground should be thoroughly moistened from time to time with water.

It is also advisable to connect these pipes to the iron framework of the station and also to any water mains, metal flumes or other heavy metal systems which are available.



The following suggestions are made for the usual size of station:

1. Place three pipes equally spaced near each outside wall, making 12 all together, and place 3 extra pipes spaced about 6 ft. apart at a point nearest the arrester;

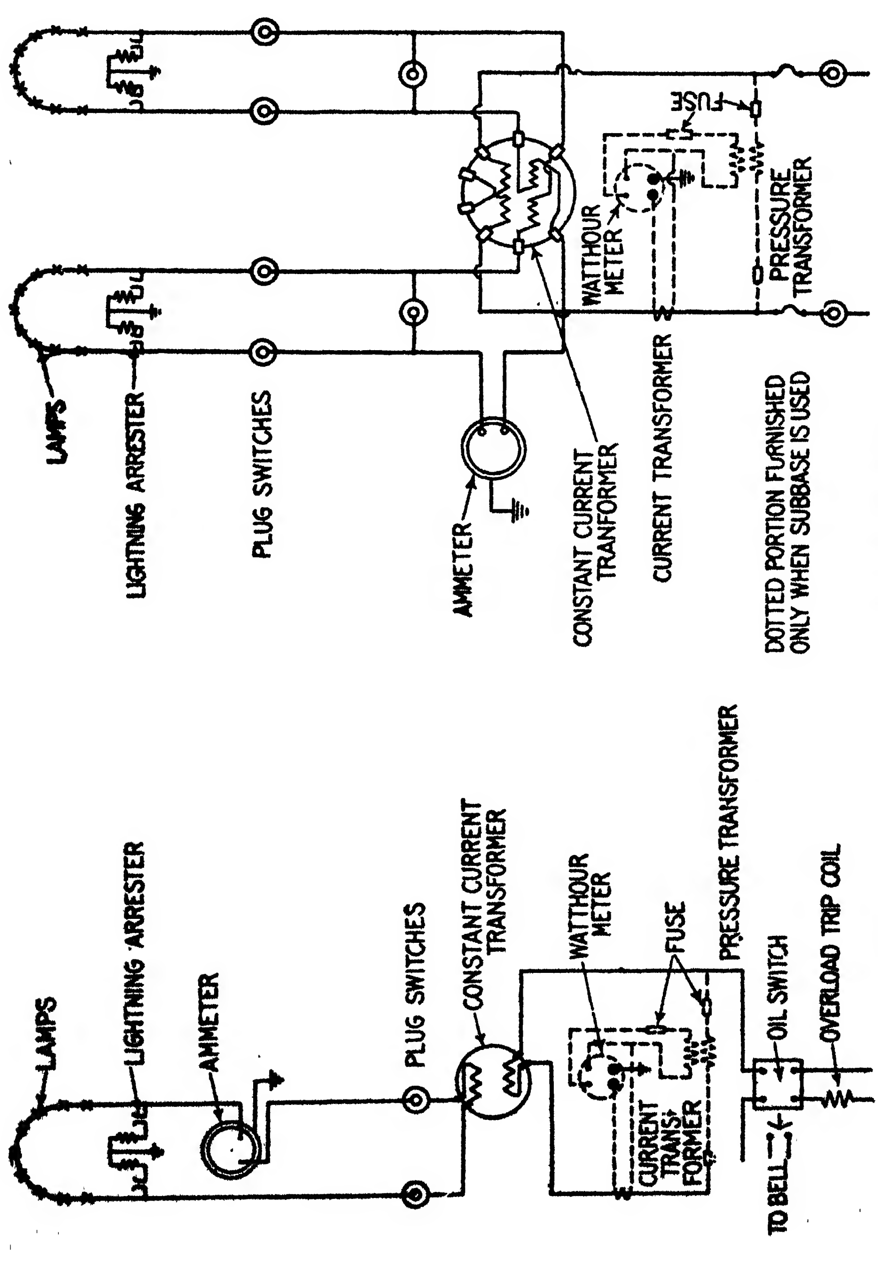
2. Where plates are placed in streams of running water, they should be buried in the mud along the bank in preference to being laid in the stream;

3. Streams with rocky bottoms are to be avoided;

4. Whenever plates are placed at any distance from the arrester, it is necessary also to drive a pipe into the earth directly beneath the arrester, thus making the ground connection as short as possible. Earth plates at a distance cannot be depended upon. Long ground wires from the station cannot be depended upon unless a lead is carried to the parallel grounding pipe installed as described above;

5. As it is advisable occasionally to examine the underground connections to see that they be in proper condition, it is well to keep on file exact plans of the location of ground plates, ground wires and pipes with a brief description so that the data can be readily referred to;

FIG. 4,434.—Steel cap for driving pipe. This prevents battering the end. The shank A, is made to fit closely the inside of the pipe to be driven and should extend into the pipe about 6 or 8 ins. The top end of the pipe fits into the groove B, of the cap, the groove being slightly wider than the thickness of the wall of the pipe and about ½ in. deep. A great many pipes may be driven before the cap will need to be renewed. A pipe may be driven with either square or flattened end to penetrate the soil, and there is not generally sufficient advantage with the flattened end to warrant the labor expended in the flattening operation. So called *ground points* may be purchased from electric power equipment dealers the points are hardened and have a shank that fits inside the pipe. These simplify driving somewhat, but not generally in sufficient degree to warrant their cost.



FIGS. 4,435 and 4,436.—Diagrams showing connections of horn type lightning arresters on series current.

6. From time to time the resistance of these ground connections should be measured to determine their condition. The resistance of a single pipe ground in good condition has an average value of about 15 ohms. A simple and satisfactory method of keeping an account of the state of the earth conditions is to divide the grounding pipes into two groups, and connect each group to the 110 volt lighting circuit with an ammeter in series.

Horn Gap Arresters. A horn gap arrester consists essentially of *two horn shaped terminals forming an air gap of variable length; one horn being connected to the line to be protected and the other to the ground usually through series resistance* as shown in fig. 4,437.

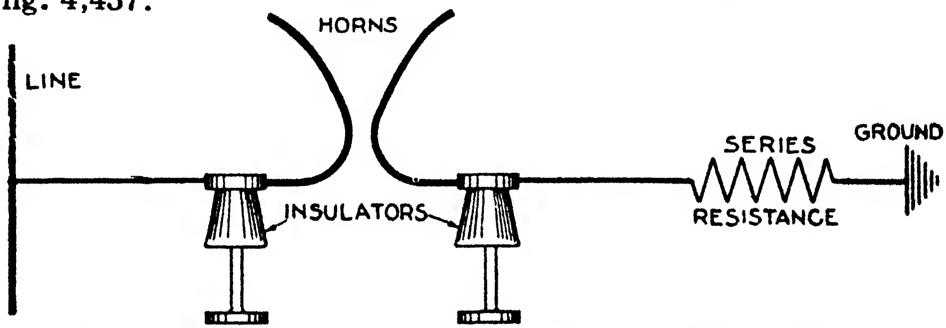


FIG. 4,437.—Horn gap arrester, diagram showing arrester and connections between line and ground. The horn type arrester was invented by Oelschlaeger for the Allgemeine Electricitaets Gesellschaft, and like the Thomson arc circuit arrester, ***its operation*** is based on the fact that *a short circuit once started at the base, the heat generated by the arc will cause it to travel upward until it becomes so attenuated that it is ruptured.* On circuits of high voltage this rupture sometimes takes a second or two, but seems to act with little disturbance of the line. ***Sometimes a water resistance*** is used, a ***choke coil being*** inserted in the circuit in series. ***In one installation*** for a 40,000 volt line, the horns were made of No. 0,000 copper wire with gap knees 2¼ to 3 or 3¼ inches. The capacity of the water resistance receptacle was 15 gallons. ***Users differ*** as to whether the water should contain salt. ***The choke coil*** can be made of about 18 turns of iron wire wound on a 6 inch cylinder.

In operation, the arc due to the line current which follows a discharge, rises between the diverging horn and becoming more and more attenuated is finally extinguished. Horn arresters should be used to protect the series rectifiers and moving coil transformers used in series lighting. They should also be used at the junction of cable and overhead series circuits.

A typical horn gap arrester is shown in fig. 4,438.

Electrolytic Arresters.—Arresters of this class are sometimes called aluminum arresters because of the property of aluminum on which their action depends; that is, it depends on the phenomenon that *a non-conducting film is formed on the surface of aluminum when immersed in certain electrolytes.*

If however, the film be exposed to a higher pressure, it may be *punctured by many minute holes; thus so reducing its resistance that a large current may pass.* When the pressure is again reduced the *holes become resealed and the film again effective.*

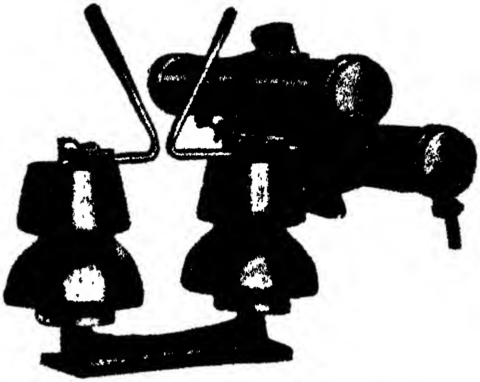


FIG. 4,438.—General Electric horn gap arrester for outdoor service. *It consists of* a horn gap, with the resistance units enclosed in porcelain tubes. These arresters are designed to be mounted on the top of the poles and above the wires to keep the arcs on the horn gaps from reaching the line wires. They are built in single pole units only.

In construction, the aluminum arrester consists essentially of a system of nested aluminum cone shaped trays, supported on porcelain and secured in frames of treated wood, arranged in a steel tank, as shown in fig. 4,439.

The system of trays is connected between the line and ground, and between line and line, a horn gap being inserted in the arrester circuit which prevents the arrester being subjected to the line voltage except when in action.

The electrolyte is poured into the cones and partly fills the space between the adjacent ones. The stack of cones with the electrolyte between them is then immersed in a tank of oil. The electrolyte between adjacent cones forms an insulation. The oil improves this insulation and prevents the evaporation of the solution.

A cylinder of insulating material concentric with the cone stack is placed between the latter and the steel tank, the object being to improve the circulation of the oil and increase the insulation between the tank and the cone stack. The arrester, as just described consists of a number of cells connected in series.

Electrolytic arresters, although many are still in use, are now fast becoming obsolete being superseded by the oxide film station type.

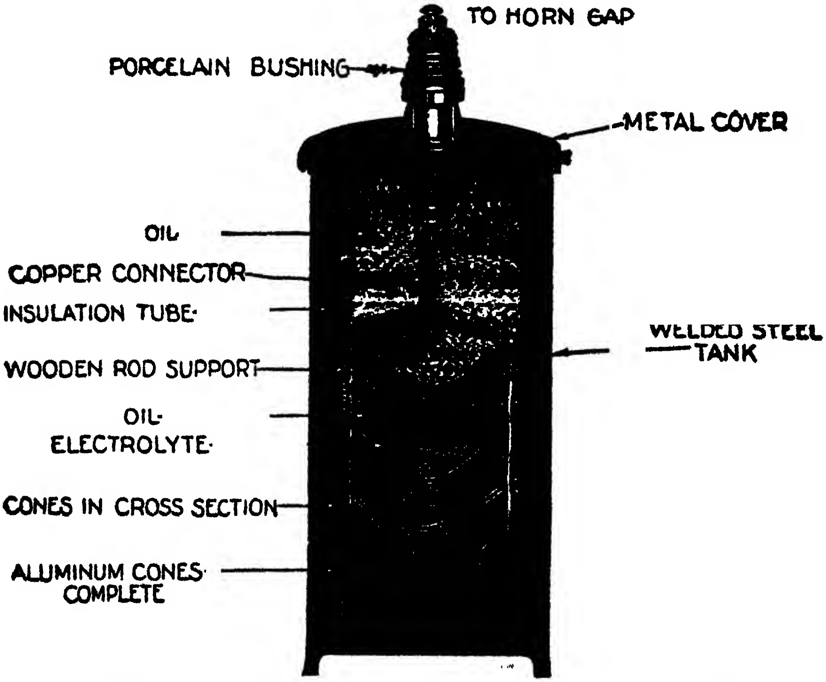


FIG. 4,439.—General Electric (aluminum) electrolytic arrester. This type is practically obsolete.

Vacuum Tube Arresters.—The design of arresters of this type is such as to give essentially *a gap in a vacuum*, the construction being shown in fig. 4,440. The gap is formed between the inner wall of a drawn metal shell and a disc electrode mounted concentric with it

The electrode is supported on a brass rod, which serves as a support as well as connection and has ample current carrying capacity. The electrode system is insulated from the tube and is rigidly supported in position by a bushing made of a special, accurately moulded, vitreous material which is unusually strong and able to withstand sudden changes of temperature. The bushing does not form the vacuum seal, however, that being made by a compound especially developed for the work. The open end of the tube is finally closed by a porcelain bushing held in place by spinning.

The tube is exhausted in a machine which solders a small hole in the end after the vacuum has been established.

The possibility of solder entering the active part of the vacuum space is prevented by a diaphragm punching. Both the electrode and the lining of the tube are made of brass. The arrester has a spark voltage of from 300 to 500 volts, direct current. Arresters of this type are used on railway signal circuits.

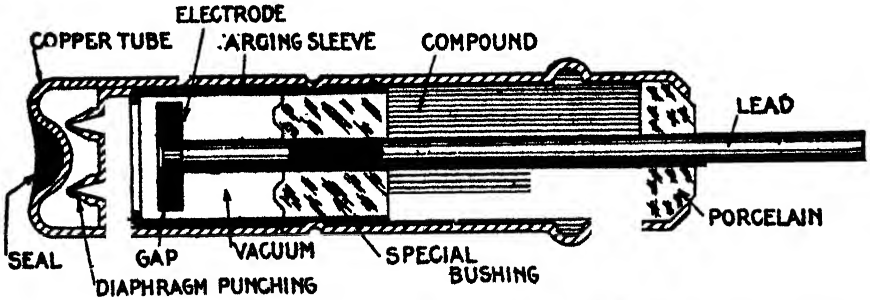


FIG. 4,440.—Sectional view of vacuum tube arrester for railway signal circuits. This arrester has a spark pressure of from 350 to 500 volts *d.c.* and an equivalent needle gap of about .005 inch. The arrester will not stand a continuous flow of current due to excessive heating, hence if there be a possibility of this due to high pressure crosses, fuses should be used.

Effective protection against lightning requires the installation of arresters having a low spark voltage, that is, the quality of discharging at low rises in voltage, and a high discharge rate, or the ability to discharge quickly a large quantity of lightning.

To meet the requirements of low spark voltage, in arresters for circuits of such low voltages, a small gap is necessary, but in order to avoid short circuits, a large gap is advisable. These opposing requirements are met by using a relatively large gap in a vacuum, because such a gap is equivalent in spark voltage to a very much smaller one in air. To obtain the same spark voltage in air a gap must be made so small that it becomes readily affected by dust, and its worth is thereby impaired.

In designing lightning arresters, great attention is usually paid to low spark voltage, but another fundamental principle, namely a high discharge rate is often neglected.

To be effective an arrester must not only discharge at small rises in voltage, but it must discharge quickly a large quantity of lightning in order that the apparatus may be immediately relieved of the lightning voltage.

An arrester may have both a low spark voltage, and a high discharge rate and yet a third fundamental principle of low maintenance may not be met. Low maintenance does not permit the arresters to be fragile, either in handling or service. As the vacuum tube arresters are of strong construction throughout, rough treatment does not affect them. Low maintenance requires the life of the tube to be long so that replacements are a minimum. This means the arrester must be so constructed that the vacuum is always retained and the current carrying parts are not affected by severe lightning discharges.

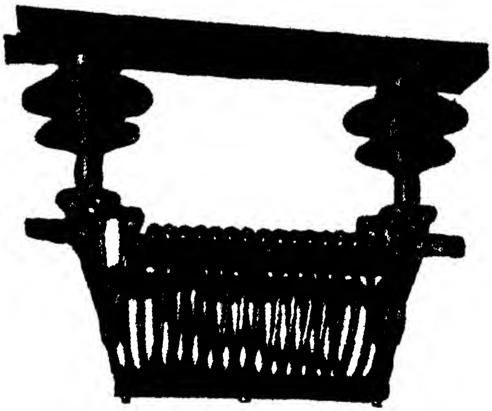


Fig. 4,441.—General Electric 400 ampere. 25,000 volt inverted choke coil.

The vacuum tube arrester will not stand a continuous flow of current as excessive heating resulting will soften the sealing compound. If there be a possibility of the circuit crossing up with one of higher voltage, fuses should be put in series with the arrester.

Choke Coils.—A lightning discharge is *of an oscillatory character and possesses the property of self induction*, accordingly

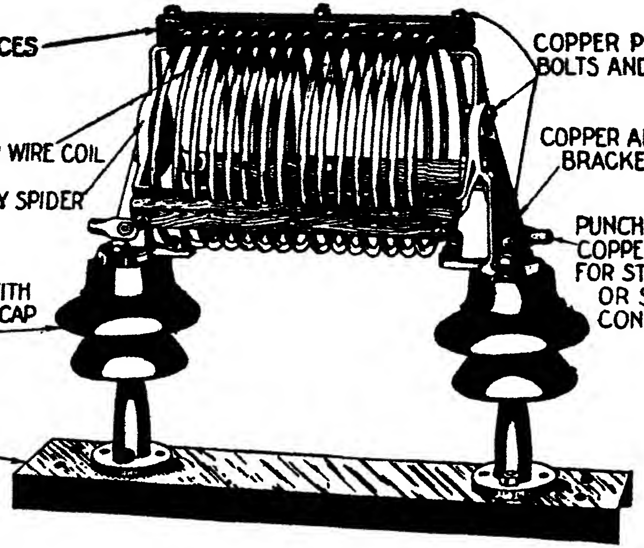


Fig. 4,442.—Typical choke coil cylindrically braced. *It consists of* a coil of bare copper wire secured throughout its length at three points around the circumference as shown. The weight of the coil proper is supported on the end spiders. The copper coil has the advantage over other materials of being practically non-corrosive and non-crystalizing. The coils with braces and end spiders are interchangeable in all mountings, for the same ampere capacity.

it passes with difficulty through coils of wire. Moreover, the frequency of oscillation of a lightning discharge being much greater than that of commercial alternating current, a coil can readily be constructed which will offer a relatively high resistance to the passage of lightning at the same time allowing free passage to all the ordinary electric currents.

The type of choke coils must be influenced by the condition of insulation in the transformers as well as by the cost, pressure regulation and the nature of the lightning protection required.

Ques. What is the primary object of a choke coil?

Ans. To hold back the lightning disturbance from the apparatus during discharge so as to permit the lightning arrester to function properly. If there be no arrester, the choke coil cannot add any protection. Accordingly, a choke coil should only be considered as an auxiliary to an arrester.

Ques. What is the principal electrical condition to be avoided with a choke coil?

Ans. Resonance. For this reason choke coils should not be used in connection with cable circuits over ½ mile in length.

Ques. If a choke coil be not used, what is the effect?

Ans. The end turns of a transformer must stand the extra voltage until the lightning arrester can perform. The choke coils therefore, help to protect the end turn of the transformer or other electrical machinery being protected.

TEST QUESTIONS

1. *What is a lightning arrester?*
2. *How does lightning affect electrical circuits?*
3. *Are lightning arresters intended to take care of direct strokes?*
4. *Upon what does the magnitude of the voltage induced on a line when a cloud discharges, depend?*
5. *What is the nature of a lightning discharge?*

6. *Give definitions of technical terms relating to lightning arresters.*
7. *Give classification of lightning arresters.*
8. *What is the difference between an arc and a spark?*
9. *What is the difference between an arrester for a grounded Y and non-grounded neutral system?*
10. *Describe a valve type arrester.*
11. *What is the follow type arrester?*
12. *Upon what does the protective ability of a lightning arrester depend?*
13. *What are air gap arresters?*
14. *Give the operating cycle of a lightning arrester.*
15. *What is a pellet arrester?*
16. *Describe the construction of a compression chamber arrester.*
17. *For what service are compression chamber arresters used?*
18. *Of what does an oxide film arrester consist?*
19. *Can oxide film lightning arresters be operated at a low voltage temporarily and later at a high voltage?*
20. *Describe the operations necessary in putting oxide film arresters in commission.*
21. *When is the pellet type of arrester used and when is the oxide film type used?*
22. *What are the essentials for giving satisfactory lightning protection to electrical machinery?*
23. *Give the method of grounding for pole type lightning arresters protecting distribution transformers.*
24. *What means are available to determine which arrester gives the best protection?*

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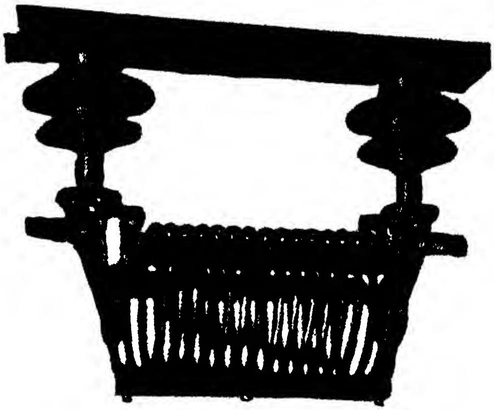

FIG. 4,441.—General Electric 400 ampere. 25,000 volt inverted choke coil.

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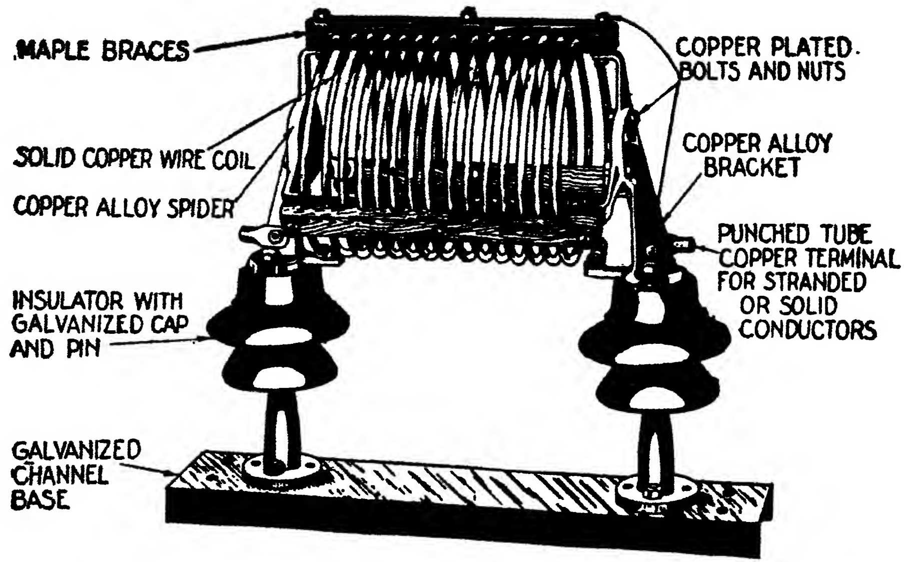

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24. *What means are available to determine which arrester gives the best protection?*

25. *Describe the requirements for grounded and ungrounded neutral circuits.*
26. *How should grounded connections be made?*
27. *Describe the horn gap arrester.*
28. *What is the construction of an electrolytic arrester?*
29. *What are vacuum tube arresters?*
30. *What is a choke coil used for?*
31. *What is the principal electrical condition to be avoided with a choke coil?*
32. *If a choke coil be not used, what is the effect?*

CHAPTER 82

A. C. Ammeters and Volt Meters

Alternating current ammeters or volt meters indicate the *virtual* values of the current or pressure respectively, that is to say, they indicate, *the square root of the mean square of a variable quantity*.

The virtual value of an alternating current or pressure *is equivalent to that of a direct current or pressure which would produce the same effect*.

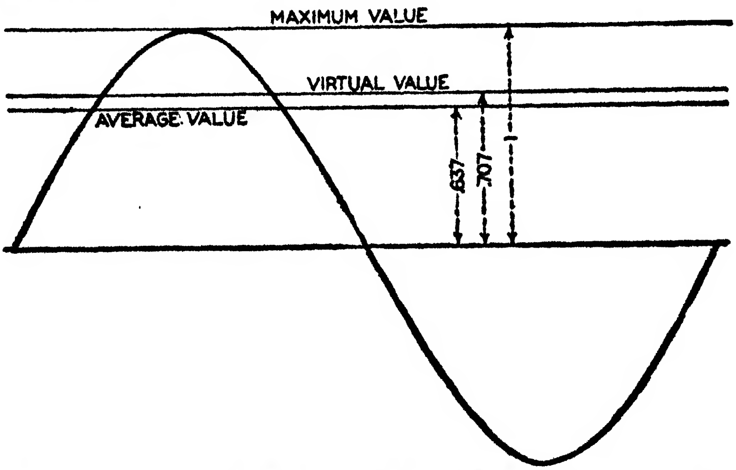


FIG. 4,443.—Sine curve of alternating current, illustrating various current or pressure values. The virtual value, or .707 × maximum value, is the value indicated by an ammeter or volt meter. Thus, if the maximum value of the current be 100 volts, the virtual value as indicated by an ammeter is 100 × .707 = 70.7 amperes.

For instance an alternating current of 10 virtual amperes will produce the same heating effect as 10 amperes direct current.

The relation of the virtual value of an alternating current to the other values is shown in fig. 4,443. When the current follows the sine law, the square root of the mean square, value of the sine functions is obtained by multiplying their maximum value by $1 \div \sqrt{2}$, or .707.

The word **effective** is commonly used *erroneously* for **virtual**, even among the best writers and the practice cannot be too strongly condemned*.† The difference between the two is illustrated on page 1,390, fig. 1,957, the mechanical analogy here given may make the distinction more marked.

In the operation of a steam engine, there are two pressures acting on the piston:

1. The *forward* pressure;

2. The *back* pressure.

The forward pressure on one side of the piston is that due to the live steam from the boiler, and the back pressure, on the other side, that which exists during the *pre-release*, *release* and *pre-admission* periods.

In order that the engine may run and do external work, it is evident that the average forward pressure must be greater than the average back pressure, and it follows that the pressure available to run the engine is the

*NOTE.—I adhere to the term virtual, as it was in use before the term efficace which was recommended in 1889 by the Paris Congress to denote the *square root of mean square value*. The corresponding English adjective is *efficacious*, but some engineers mistranslate it with the word *effective*. I adhere to the term virtual mainly because effective is required in its usual meaning in kinematics to represent the resolved part of a force which acts obliquely to the line of motion, the effective force being the whole force multiplied by the cosine of the angle at which is acts with respect to the direction of motion.—*S. P. Thompson*

†NOTE.—The author adheres to the term *virtual* because in mechanics the adjective *effective* is used to denote the difference of two opposing forces; for instance, at any instant in the operation of a steam engine, *effective pressure = average forward pressure − average back pressure*, hence, to be consistent in nomenclature, the term effective cannot be used for the forward or virtual pressure, that is, the pressure impressed on an electric circuit.

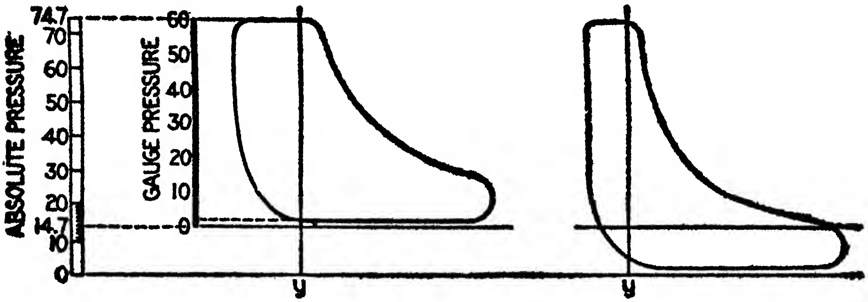
difference between these two pressures, ***this pressure difference being known as the effective pressure,*** that is to say

effective pressure = average forward pressure — average back pressure

Thus, electrically speaking, the effective voltage is that voltage which is available for driving electricity around the circuit, that is,

effective volts = virtual volts — back volts
= virtual pressure — (virtual pressure — drop)

In the case of the steam engine, the forward pressure absolute, that is, measured from a perfect vacuum is the virtual pressure (not consider-



FIGS. 4,444 and 4,445.—Steam engine ***indicator cards illustrating by mechanical analogy,*** the misuse of the term ***effective*** as applied to the pressure of an alternating current. The card fig. 4,444, represents the performance of a steam engine taking steam at 60 lbs. (gauge) pressure and exhausting into the atmosphere. The exhaust line being above the atmospheric line shows that the friction encountered by the steam in flowing through the exhaust pipe produces a back pressure of two lbs. Hence at the instant represented by the ordinate *y*, the ***effective pressure*** is 60 − 2 = 58 lbs., or using ***absolute pressures,*** 74.7 − 16.7 = 58 lbs., the ***virtual pressure*** being 60 lbs. gauge, or 74.7 lbs. absolute. Now, the ***back pressure*** may be considerably reduced by exhausting into a condenser as represented by the card, fig. 4,445. Here, most of the pressure of the atmosphere is removed from the exhaust, and at the instant *y*, the back pressure is only 6 lbs., and the effective pressure 74.7 − 6 = 68.7 lbs. Thus, in the two cases ***for the same virtual pressure*** of 60 lbs. gauge or 74.7 lbs. absolute, ***the effective pressures are*** 58 lbs. and 68.7 lbs. respectively.

ing the source). The back pressure may vary widely for different conditions of operation as illustrated in figs. 4,444 and 4,445.

In the measurement of alternating current, it is not the average, or maximum value of the current wave that defines the current commercially, but the *square root of the mean square* value, because this gives the equivalent heating effect referred to direct current. There are several types of instrument for

measuring alternating current, and they may be classified as

1. Electro-magnetic (moving iron);
2. Hot wire;
3. Induction;
4. Dynamometer.

Electro-magnetic or Moving Iron Instruments.—This type of instrument depends for its action upon the pull of flux in endeavoring to reduce the reluctance of its path. This pull is proportional to the product of the flux and the current, and

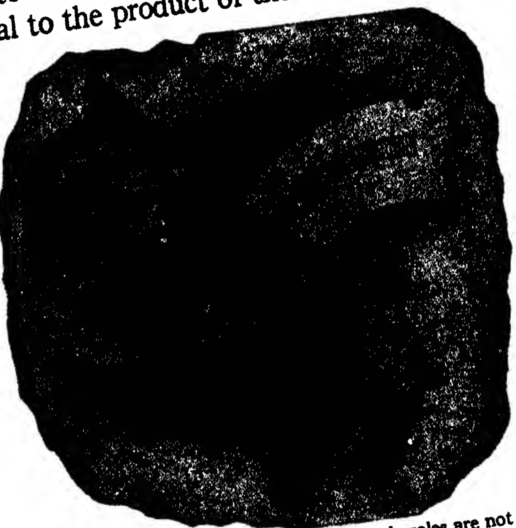


FIG. 4,446.—A *calibrated* scale. This means that printed scales are not employed, but each instrument has its scale divisions plotted by actual comparison with standards, after which the division lines are inked in by a draughtsman. There are makes of direct current instruments employing printed scales in which the scale deflections are fairly accurate, even though the scales are printed, but printed scales should not be used on alternating current instruments.

so long as no part of the magnetic circuit becomes saturated, the flux is proportional to the current, hence the pull is proportional to the square of the current to be measured.

NOTE.—*One of the earliest difficulties* in connection with the introduction of the alternating current system was the lack of suitable measuring instruments. The early attempts to develop *a.c.* instruments resulted in very crude instruments which did not compare favorably with the *d.c.* instruments of that period. Some of the old instruments may be remembered by pioneers of the industry.

An objection to the moving iron type instruments is that they are not independent of the frequency, wave form, or temperature and external magnetic fields may affect the readings temporarily.

There are several forms of moving iron ammeters, which may be classified as:

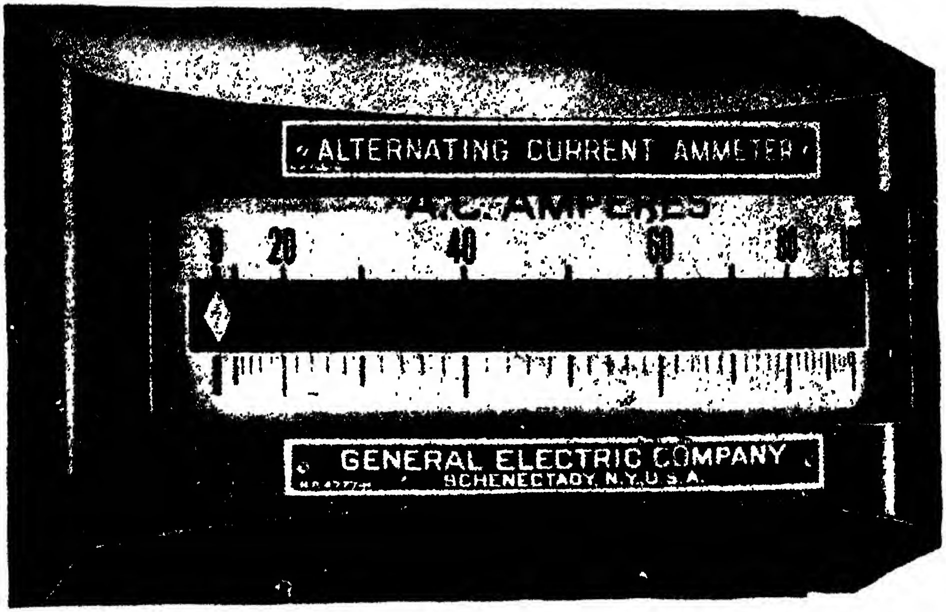


FIG. 4,447.—General Electric horizontal edgewise type ammeter.

1. Plunger;
2. Inclined coil;
3. Magnetic vane.

Plunger Type.—This form of electro-magnetic or moving iron instrument consists of a series coil and a soft iron plunger forming a solenoid, the plunger is so suspended that the magnetic pull due to the current flowing through the coil is balanced by gravity, as shown in fig. 4,448.

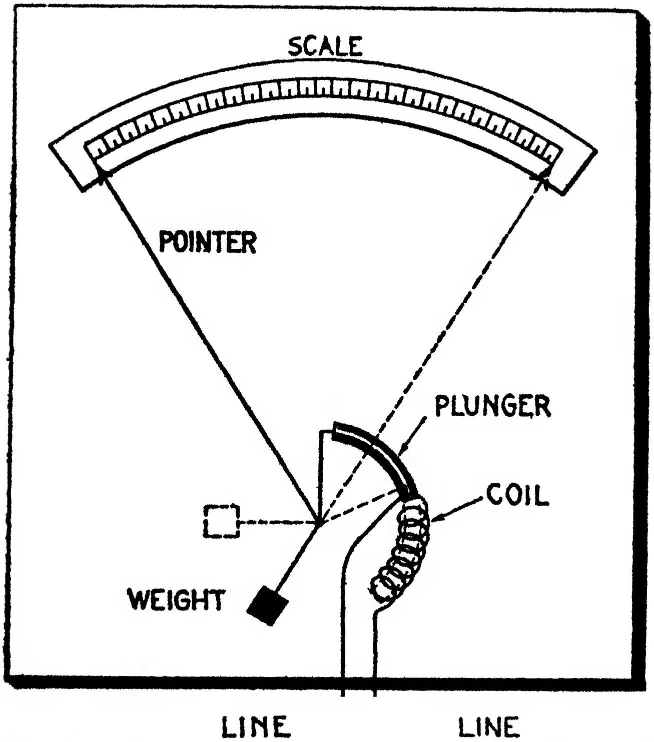


FIG. 4,448.—Plunger form of electro-magnetic or moving iron type of ammeter.

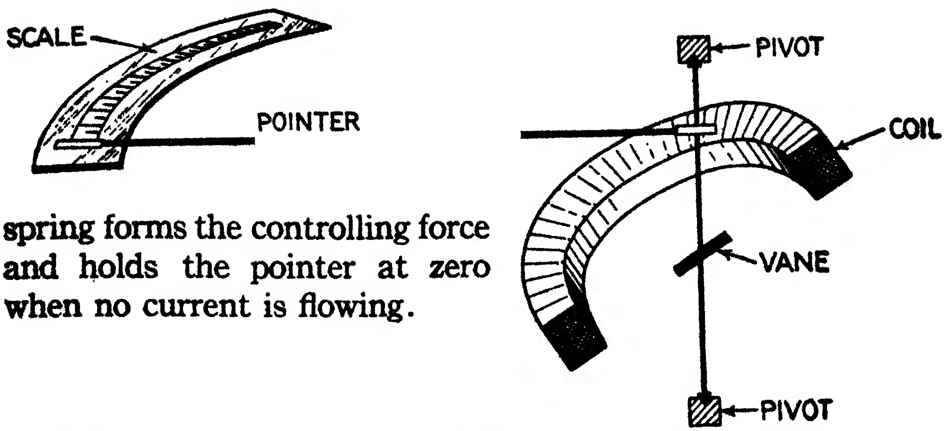
In order to adapt the instrument to alternating current the plunger should be laminated to avoid eddy currents.

The scale is not uniform and should be hand made and calibrated under the conditions for which it is to be used.

An objection to the plunger type ammeter is that they are large and expensive because the coil carries all the current. In installing a plunger ammeter, the instrument should be carefully leveled, because gravity is the controlling force.

Inclined Coil Type.—This form of electro-magnetic or moving iron instrument consists of a coil mounted at an angle to a shaft carrying a vane and pointer, as shown in fig. 4,449. A

NOTE.—*The early volt meter* had a lever, on one end of which was a weight, adjustable by the number of shot in a brass cylinder, and on the other end, was an iron wire plunger which extended into a solenoid. Incandescent lamps were used as resistance in series with the solenoid. When the applied voltage was at a normal value, the pull of the solenoid was just sufficient to cause the pointer attached to the lever to point vertically. There were no graduations on the scale. This volt meter was soon superseded by one in which German silver resistance replaced the lamps. The needle of the early ammeter traversed a circular dial under the action of a plunger in the solenoid which carried the main current. In the latter form, the mechanism was simpler, and the deflection was indicated on a scale near the bottom of the instrument.



spring forms the controlling force and holds the pointer at zero when no current is flowing.

FIG. 4,449.—Inclined coil form of electro-magnetic or moving iron instrument.

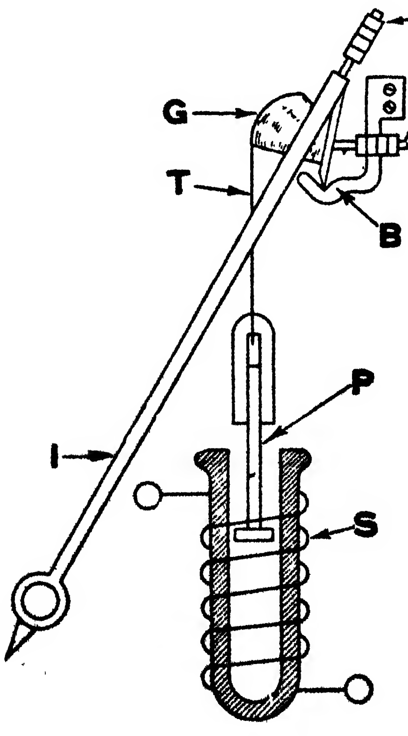


FIG. 4,450.—Kelvin solenoid principle. This utilizes the attracting or "sucking" effect of an energized solenoid to pull an iron core, attached to a suitably pivoted pointer, and produce direct deflection over a calibrated scale. *In construction* S, is the winding of the main solenoid, wound around the iron plunger P, which moves in a glass tube containing oil to damp the motion. The bearings B, are rigidly attached to the base casting. The pointer I, is attached to a steel knife edge, which rests in the V shaped highly polished bearings B. Also attached to the pointer and knife edge is the circle segment G, with a groove in its circumference, in which runs the fine silk thread T, connecting the plunger to the movement. *In operation,* as soon as current flows through the solenoid S, it exerts a downward pulling effect on the plunger, which, in turn, pulls on the segment G, and produces a movement of the pointer. The knife edge bearings simply rock as the pointer moves, thus producing an inexpensive frictionless bearing without resorting to the use of pivots and jewels. The counterweights C and C', oppose this motion; therefore by suitably marking the scale, the deflection becomes a measure of the current.

In operation, when a current is passed through the coil, the iron tends to take up a position with its longest sides parallel to the lines of force, which results in the shaft being rotated and the pointer moved on the dial, the amount of movement depending upon the strength of the current in the coil.

Magnetic Vane Type.—This form of electro-magnetic or moving iron instrument consists of *a small piece of soft iron or* **vane** mounted on *a shaft that is pivoted a little off the center of*

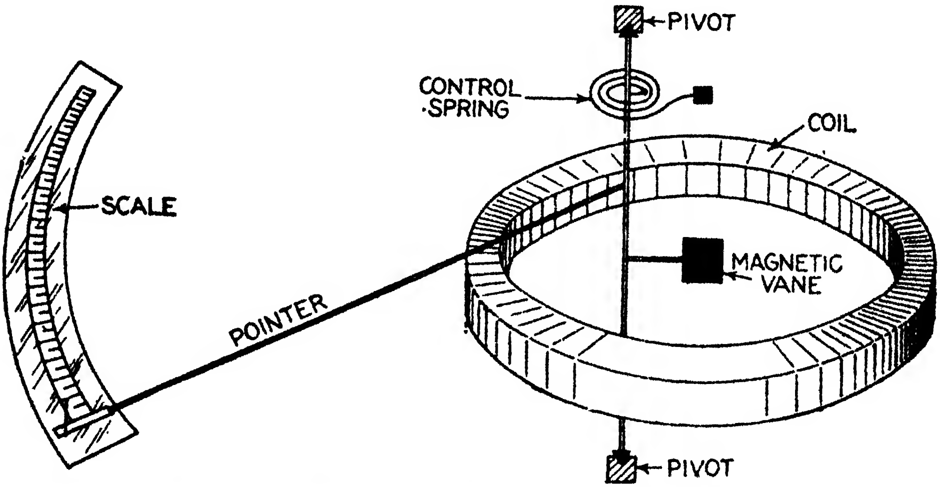


Fig. 4,451.—Magnetic vane form of electro-magnetic or moving iron instrument.

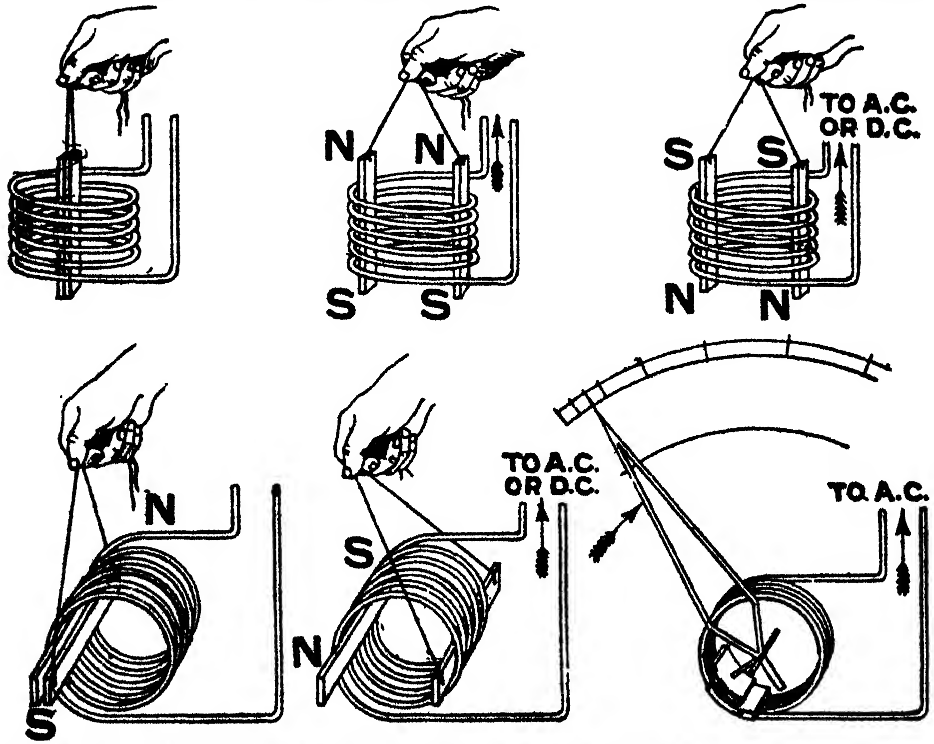
a coil as shown in fig. 4,451, and carrying a pointer which moves over a scale.

In operation, a piece of soft iron placed in a magnetic field and free to move, will move into such position as to conduct the maximum number of lines of force.

The current to be measured is passed around the coil, producing a magnetic field through the center of the coil. The magnetic field inside the coil is strongest near the inner edge, hence, the vane will move against the restraining force of a spring so that the distance between it and the inner edge of the coil will be as small as possible.

The operation of moving iron instruments of the plunger type may be explained by saying that the current flowing in the coil produces a pole at its end and induces an unlike pole at the end of the plunger nearest the coil, thus attracting the plunger, as illustrated in fig. 4,460.

Hot Wire Instruments.—Ammeters and volt meters of this class depend for their operation on the expansion and contraction of a fine wire carrying either the current to be measured



Figs. 4,452 to 4,457.—Principle of moving iron repulsion instruments. If direct current be sent through the two small pieces of iron suspended vertically within a solenoid by thread as in fig. 4,452, they will become magnetized and since they are in the same magnetic field both will be affected the same, and will repel each other as in fig. 4,453. If the current be sent through the solenoid in the opposite direction the result will be the same. Next if the coil be laid on its side and the two pieces of iron be placed within it horizontally as in fig. 4,455, one fixed and the other free to move and a current be passed through the solenoids the two pieces of iron will repel each other. If an *a. c.* be used instead of *d. c.* and it reverse with sufficient frequency, the polarity of the two pieces of iron will reverse in step with the current and they will repel each other as before. Hence on employing this principle in instrument construction two curved pieces of iron are used, one fixed and the other pivoted so that it will rotate when electrically repelled from the fixed iron as in fig. 4,457. A pointer attached to the movable iron moves over a graduated scale.

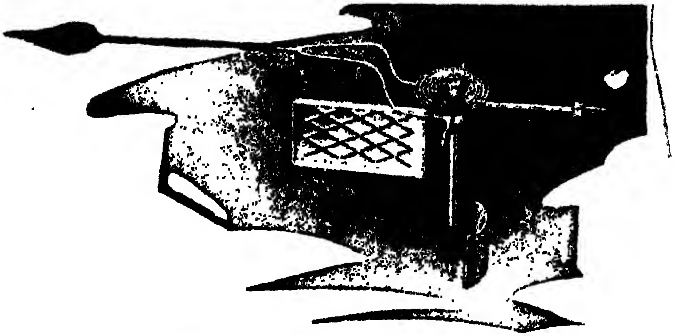


FIG. 4,458.—Jewell moving element of repulsion iron vane type instrument. *It consists of* an aluminum shaft to which is attached the iron vane, the balance cross, the pointer and the spring clip. The 7 in. instrument moving element can be seen to consist of an aluminum shaft with a shoulder swaged on its upper end, on which rests the fan support, the balance cross and spring clip, the pointer being attached to the forward end of the balance cross. The iron vane with its support is riveted to the shaft with a tiny rivet, which makes it a permanent assembly.

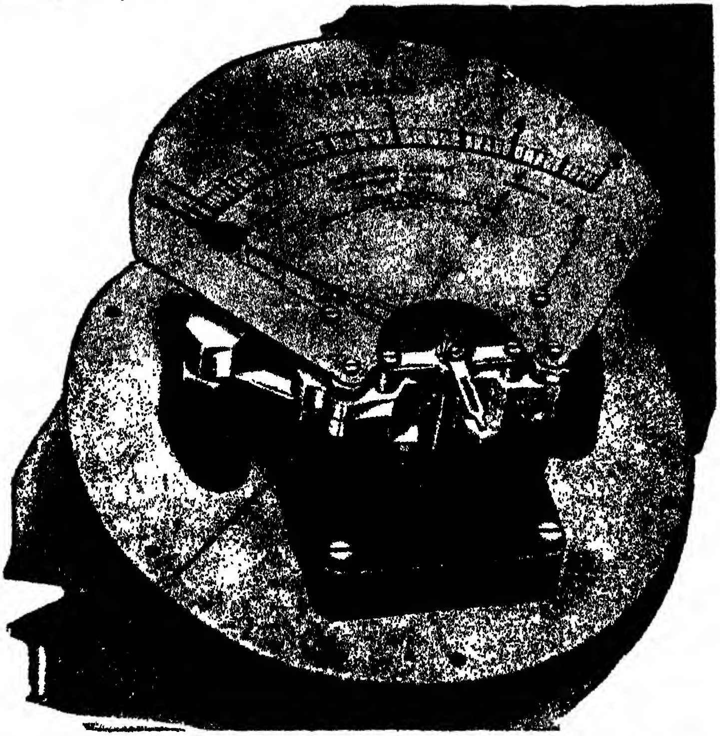


FIG. 4,459.—Jewell repulsion iron vane type instrument. *The principle of operation* is the repulsion between *two iron vanes which are magnetized by the surrounding coil.*

The expansion or contraction of the wire is caused by temperature changes, which in turn are due to the heating effect of the current flowing through the wire.

Since the variations in the length of the wire are extremely small, considerable magnification is necessary. Pulleys or levers are sometimes used to multiply the motion, and sometimes the arrangement shown in fig. 4,461.

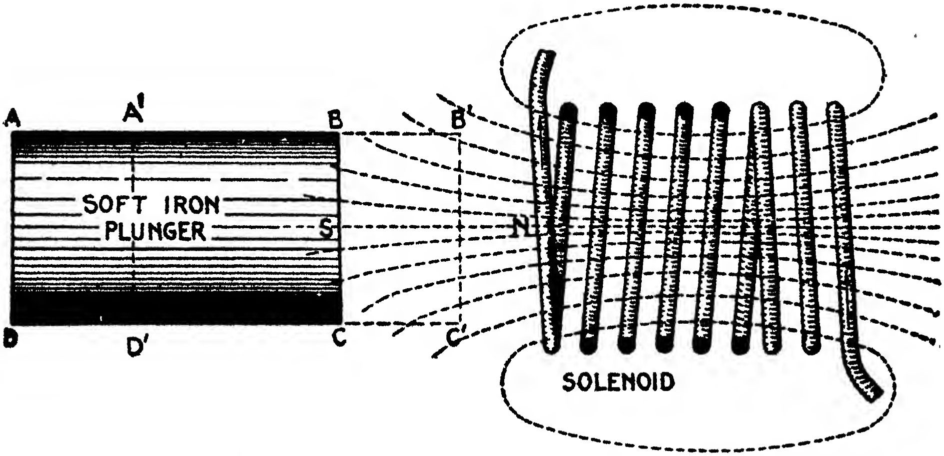


FIG. 4,460.—Solenoid and plunger *illustrating the operation of moving iron instruments.* When a current flows through the coil, a field is set up as indicated by the dotted lines of force. The current flowing in the direction indicated by the arrow induces a north pole at N, which in turn induces a south pole in the plunger at S, thus attracting the plunger. *The effect of the field upon the plunger* may also be stated by saying that *it tends to cause the plunger to move in a direction so as to conduct the maximum number of lines of force, that is, toward the solenoid.* Thus if ABCD, be the initial position of the plunger only five lines of force pass through it; should it move to the position A'B'C'D', the number of lines passing through it will then be 9, assuming the field to remain unchanged.

As here shown A, is the active wire carrying the current to be measured and stretched between the terminals T and T'. It is pulled taut at its middle point by another wire C, which carries no current, and is in its turn, kept tight by a thread passing round the pulley D, attached to the pointer spindle, the whole system being kept in tension by the spring E.

Hot wire instruments are equally accurate with alternating or direct current, but have cramped scales (since the deflection is proportional to the square of the current), and are liable to creep owing to unequal expansion of the parts. There is also the danger that they may be burnt

out with even comparatively small overloads. They are not affected by magnetic fields but consume more current than the other types, these readings are inaccurate near either end of the scale.

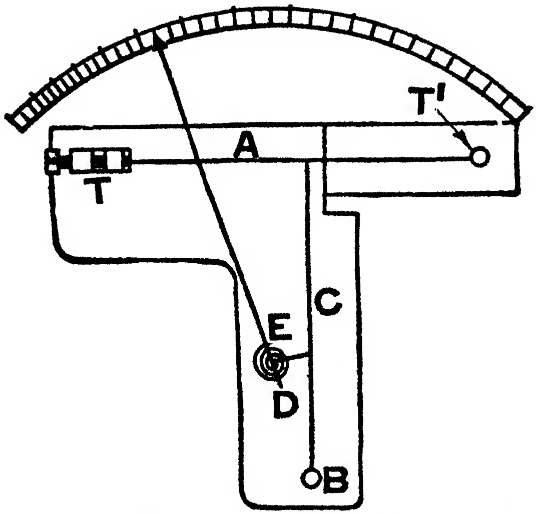
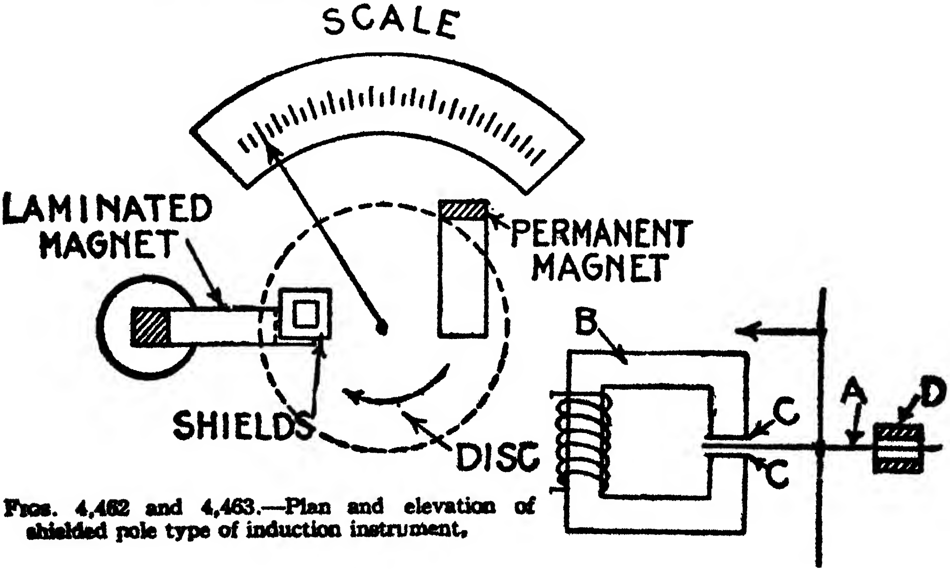


FIG. 4,461.—Diagram illustrating the principle of hot wire instruments. The essential parts are the active wire A, stretched between terminals T and T', tension wire C, spring E, and pulley D, to which is attached the pointer.



FIGS. 4,462 and 4,463.—Plan and elevation of shielded pole type of induction instrument.

Induction Instruments.—These were invented by Ferraris, and are sometimes called after him. They are for alternating current only, and there are two forms:

1. Shielded pole type;
2. Rotary field type.

Shielded Pole Type.—This form of induction instrument, as shown in figs. 4,462, and 4,463 consists, essentially, of a disc

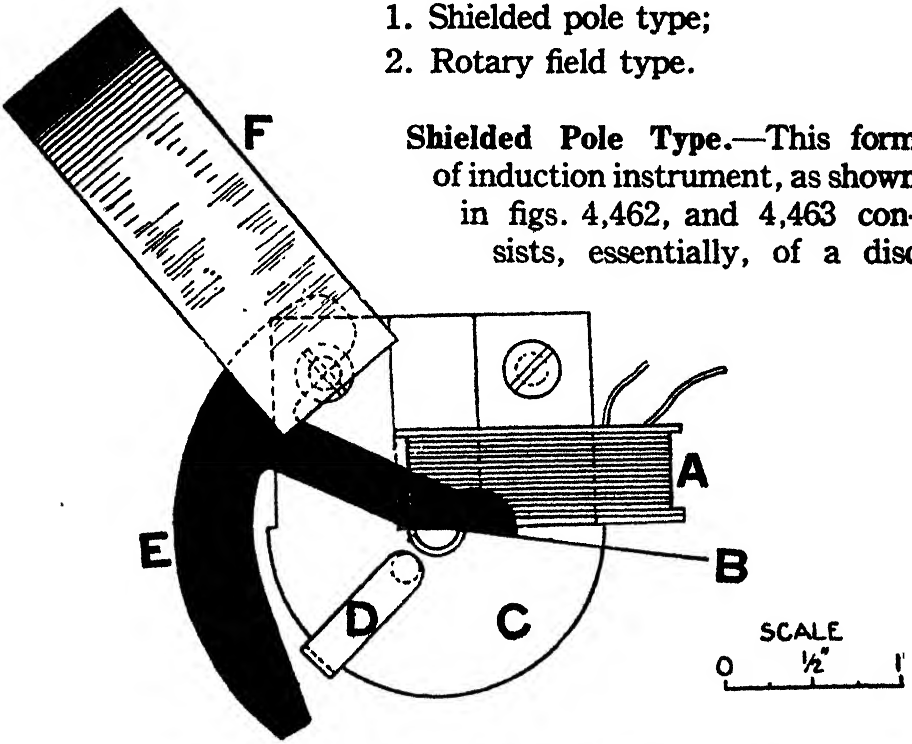


FIG. 4,464.—Diagram of Hoskins modified induction type instrument in which the torque is produced from the direct repulsion between a primary and a secondary, or induced current. As shown, the instrument embodies the principle of a short circuited transformer, consisting of a primary or exciting coil A, a secondary or closed coil B, linked in inductive relation to the primary by a laminated iron core C, constructed to give a completely closed magnetic circuit, that is, without air gap. The secondary is so mounted with respect to the primary as to have a movement under the influence of their mutual repulsion when the primary is traversed by an alternating current. This movement of the secondary B, is opposed by a spiral spring, so that the extent of movement will be dependent upon and will indicate the strength of the primary current. To increase the sensitiveness of the instrument and also to adjust the contour of the scale, an adjustable secondary D, which has an attraction effect upon the coil B, is provided upon the core. The effect of this coil is inversely proportional to its distance from the end of the swing of the coil B. The vane, E, which is a part of the stamping B, is adjusted to swing freely and with a large amount of clearance, between the poles of a permanent magnet F, which acts as a damper on the oscillation of the moving element, but does not cause any friction or affect the accuracy of the calibration. The primary, like that of a transformer, is an independent electrical circuit and mav be highly insulated.

A, or sometimes a drum and a laminated magnet B. Covering some two-thirds of the pole faces are two copper plates or shields C, and a permanent magnet D.

In operation eddy currents are induced in the two copper plates or shields C, which attract those in the disc, producing in consequence a torque in the direction shown by the arrow, against the opposing action of a spring. Magnet D, damps the oscillations.

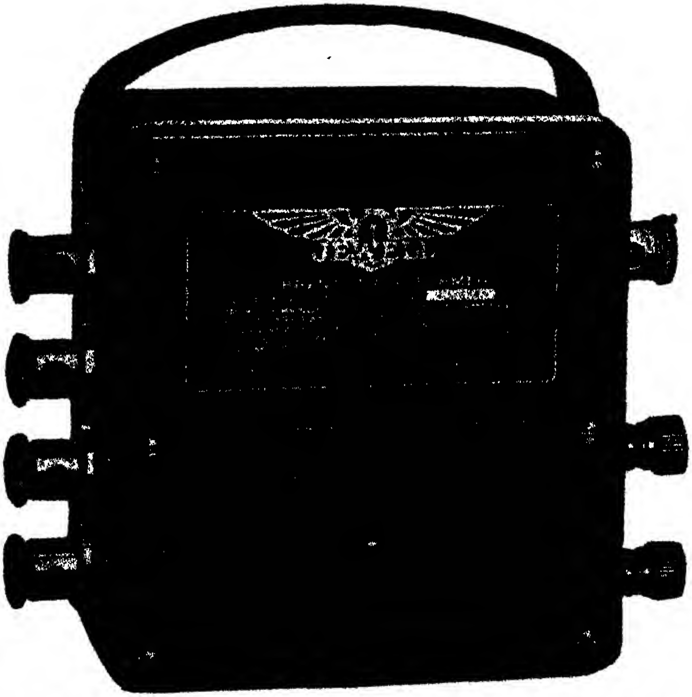


FIG. 4,465.—Jewell master current transformer. It has been designed to fill the requirements of current measurement up to 100 amperes in connection with a 5 ampere instrument. It is rated at 10 volt amperes and this rating permits the use of a watt meter and ammeter of maximum accuracy in series.

Rotary Field Type.—The parts of this form of induction instrument are arranged similar to those of watt meters, the necessary split phase being produced by dividing the current into two circuits, one inductive and the other non-inductive, or a definite proportion of that current.

Current and Potential Transformers.—Where switchboard instruments are to be used on currents higher than the listed internal or self-contained values, or in any case where the voltage is over 750 volts, it is universal practice to use transformers.

Current transformers are supplied to reduce the line current by a definite ratio so that a 5 ampere instrument may be used. They also serve to insulate the instrument from the voltage of the line, and should always be selected so that their voltage rating covers the voltage on which they are to be used.

Potential transformers are used to reduce the line voltage by a definite ratio so that the instruments having a nominal voltage range of 150 volts may be used.

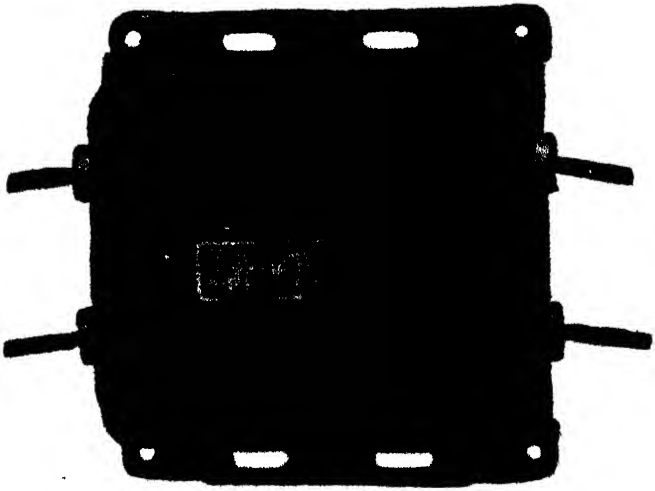


Fig. 4,466.—Jewell potential transformer. Rated at 25 volt amperes, and will amply take care of the load of several instruments. The relative polarity of the terminals is clearly marked so that watt meters and power factor meters can be connected up, knowing that they will indicate correctly.

In selecting current transformers the endeavor should be to make the primary rating equal as nearly as possible the full load current to be measured. It is not good practice to use an instrument transformer with a range considerably higher than normal load, because the secondary current is then low and in the case of power factor meters and watt meters

the torque will be low and the ratio of transformation does not hold so well as at low values.

Example.—A 100 *h.p.* 3 phase, 220 volt motor will draw about 250 amperes at full load. A 250 ampere transformer would be quite satisfactory for this application and would take care of occasional overloads with perfect satisfaction.

Current transformers are universally designed for a secondary current of 5 amperes for the nominal primary current rating. Special transformers should be avoided wherever possible because they are expensive to design and build.

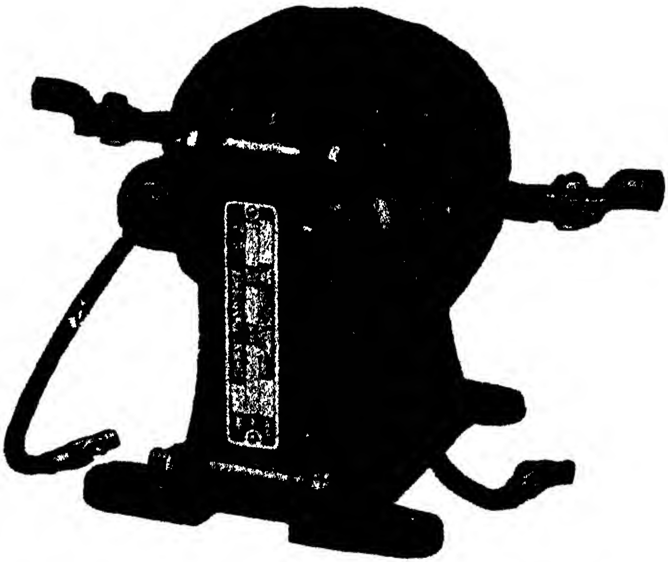


Fig. 4,467.—Jewell two wire current transformer. Rated capacities from 5 to 400 amperes inclusive, for a nominal secondary reading of 5 amperes and is rated at 15 volt amperes. This type will function satisfactorily at any frequency from 25 to 133 cycles and is insulated for 3,300 volts.

Where overloads are expected and it is desired to read them on the instrument, it is entirely in order to use a 6 or 7 ampere instrument to read that overload. *For example,* in the case cited above, instead of calibrating the instrument to 5 amperes with a 250 ampere scale, it could be calibrated to 6 amperes with a 300 ampere scale. This is regular practice on many applications. Watt meters may also be calibrated on a basis of this sort, using a higher current for the nominal reading, thus making the watt range of the scale sufficiently high to cover occasional overloads.

Current transformers have a nominal ratio as given in manufacturers' listing. Ratio and phase angle curves are not regularly furnished, but are available when desired in the form of typical curves. Transformers run so nearly uniform that curves on specific units are rarely necessary and the typical curves will usually cover all requirements.

Potential transformers are rated for a nominal secondary voltage of 110 volts. That is, a 220 volt transformer has a secondary voltage of 110 volts, and has a ratio of 2:1. Where the primary voltage is rated in terms of 115 volts, then the secondary is also 115 volts, so that an even ratio is always supplied.

Often 2300/110 volt transformers are selected, which is in error; what is actually supplied by the manufacturer is a 2300/115 volt transformer, which is identical with a 200/100 volt transformer.

TEST QUESTIONS

1. *What kind of values of the current or pressure do a.c. ammeters and volt meters indicate?*
2. *What is the virtual value of an a.c. current or pressure?*
3. *Describe a sine curve and indicate the various currents or pressure values.*
4. *Name several types of a.c. ammeters and volt meters.*
5. *Describe the electro-magnetic or moving iron instruments.*
6. *Name two forms of moving iron ammeters.*
7. *Describe the plunger type.*
8. *How does the inclined type work?*
9. *Of what does a magnetic vane type consist?*
10. *How does a magnetic vane instrument work?*
11. *Describe the construction and operation of hot wire instruments.*

12. *Who invented the induction type instruments?*
13. *Name two types of induction instruments.*
14. *Of what does the shielded pole type induction instrument consist?*
15. *Describe Hoskins' modified induction instrument.*
16. *How does the rotary field type of induction instrument work?*
17. *What are current and potential transformers used for?*
18. *How should current transformers be selected?*
19. *How are potential transformers rated?*

CHAPTER 83

Dynamometers

A dynamometer is used *to measure volts, amperes, or watts,* its operation depends on *the reaction between two coils when the current to be measured is passed through them.* One of the coils is fixed and the other movable.

The fixed coil is composed of a number of turns of wire, and fastened to a vertical support and is surrounded by a movable coil composed of a few turns or often of only one turn of wire.

The movable coil is suspended by a thread and a spiral spring attached to a tortion head which passes through the center of a dial. The ends of the movable coil dip into mercury cups, which act as pivots and electrical contacts, making connection with one end of the fixed coil and one terminal of the instrument as shown.

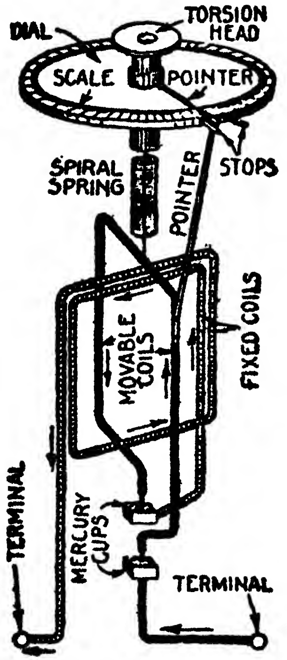
The tortion head can be turned so as to place the planes of the coils at right angles to each other and to apply tortion to the spring to oppose the deflection of the movable coil for this position when a current is passed through the coils.

A pointer attached to the movable coil indicates its position on the graduated dial between the two stops. Another pointer attached to the tortion head performs a similar function.

In the operation of a dynamometer when current is passed through both coils, *the movable coil is deflected against one of the stop pins, then the tortion head is turned to oppose the movement until the deflection has been overcome and the coil brought back to its original position.*

The angle through which the tortion head was turned, being proportional to the square root of the angle of tortion, the current strength in amperes is equal to the square root of the angle of tortion *multiplied by a calculated constant*, furnished by the maker of the instrument.

When measuring *watts*, a dynamometer should be so arranged that *one coil carries the main current, and the other a small current which is proportional to the pressure.*



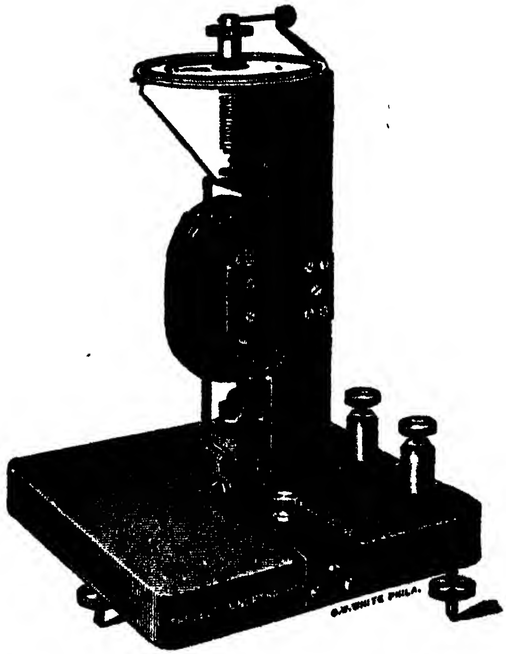


FIG. 4,468.—Diagram of Siemens' dynamometer. *It consists of* two coils on a common axis but set in planes at right angles to each other in such a way that a torque is produced between the two coils which measures the product of their currents. This torque is measured by twisting a spiral spring through a measured angle of such degree that the coils shall resume their original relative positions. *When constructed as a volt meter,* both coils are wound with a large number of turns of fine wire, making the instrument sensitive to small currents. Then by connecting a high resistance in series with the instrument, it can be connected across the terminals of a circuit whose voltage is to be measured. *When constructed as a watt meter,* one coil is wound so as to carry the main current and the other made with many turns of fine wire of high resistance suitable for connecting across the circuit.

FIG. 4,469.—Leeds and Northrup *electro-dynamometer. It is a reliable instrument for the urement of alternating currents of commercial frequencies.*

No iron or other magnetic material should be used in the construction of a dynamometer because of the hysteresis losses occasioned thereby. The frame should be of non-conducting material so as to avoid eddy currents.

For the precision measurement of alternating current and voltage, and for the measurement of watts and other relations between two quantities the dynamometer type of movement is necessary.

The essential parts of a dynamometer movement are the fixed coils and their supports, the moving element and the damping means which

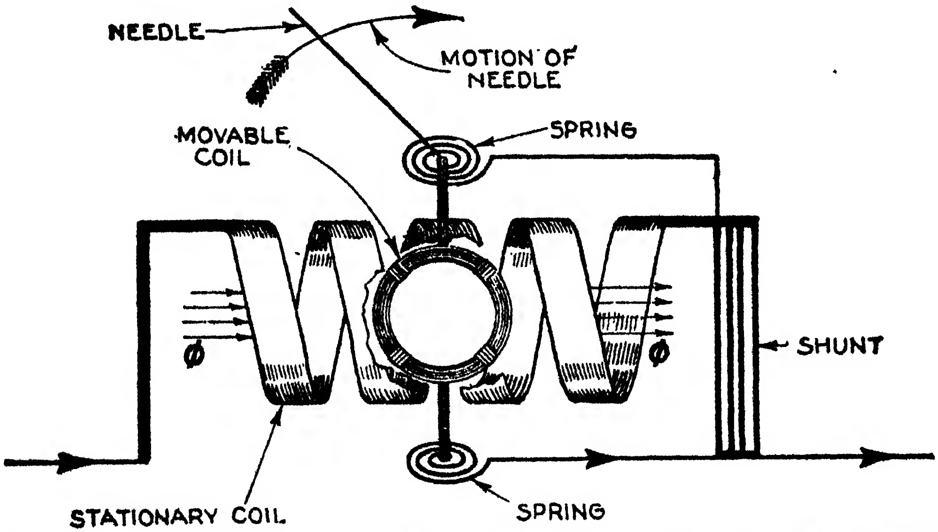


FIG. 4,470.—Dynamometer type ammeter. If the stationary and movable coils *be connected in series and shunted*, the instrument is an ammeter; if the two coils *be in series and also in series with a high resistance multiplier*, the instrument is a volt meter; and if the low resistance stationary coil *be in the line in series and the movable coil be in series with a high resistance and then placed across the line*, the instrument is a direct reading watt meter. The torque in any instrument: $T = k\phi I$ (motor action formula). If the two coils be in series, then the ϕ set up by the stationary coil is proportional to I, and the torque therefore is proportional to I^2. Therefore for ammeters and volt meters this instrument has a "squared scale." Such an instrument may be used on alternating current, because if the current change to negative, then ϕ is negative and I, is negative and the direction of the torque from the left hand rule for motor action, remains the same. The instrument may be made approximately dead beat by aluminum vanes which move in air compartments. As the needle moves, the vanes move in the compartment and the air moving from one side to the other of the vane slows down the motion so that the needle does not attempt to follow all the minute fluctuations of the current. In the diagram the stationary coil carries all the current and sets up the flux ϕ. The movable coil is shunted by the shunt as shown. The torque set up between the coils tends to twist the movable coil and needle to the right (clockwise looking down on the coil) and this motion is opposed by the two springs.

in general is similar to the fan used in the iron vane movement except that the fan is double and operates in a double air chamber.

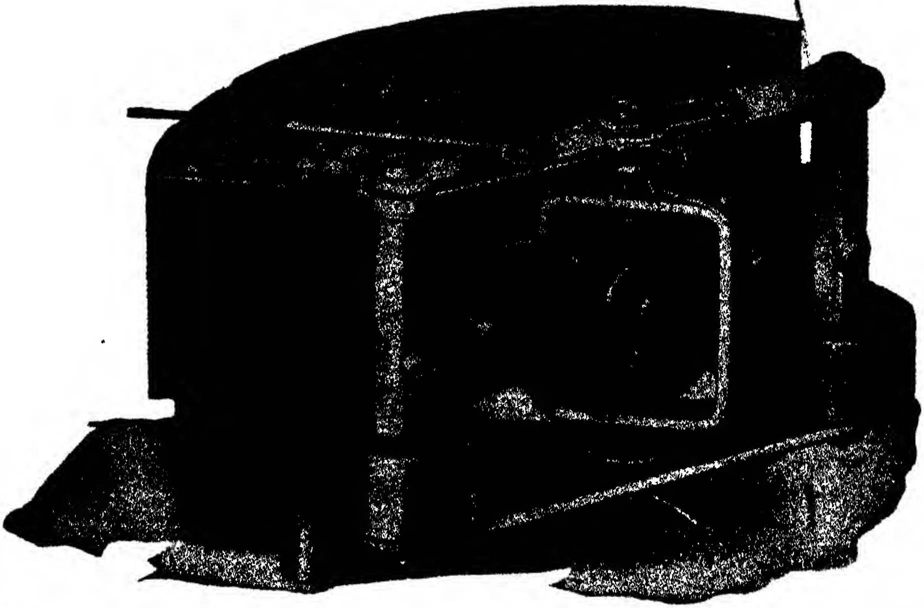


FIG. 4,471.—Hickok dynamometer movement for ammeters, volt meters and watt meters. It contains but two coils, a fixed field coil and a moving coil surrounding the field coil in such a manner that the resultant torque between the two coils is uniform throughout a 90° movement of the moving coil, which gives a uniform scale in the watt meters and a uniformly increasing scale in the volt meters and ammeters. The frame work of the movement is cast in one piece from an insulating material and contains a semi-circular chamber in which moves an aluminum dampening vane which is attached to the moving coil making the instrument very "dead beat."

In the use of the electro-dynamometer principle for a basis of design for alternating current instruments, recourse was had to the simplest and most direct known manifestation of the presence of electrical currents by which these currents may be measured. In other words, the moving coil dynamometer principle of operation is the most direct method for measuring currents and their relations to one another and, at the same time, results in the best answer to the problem of producing instruments which would be of most general applicability and of ideal construction.

This principle of operation is used with only a slight modification for the production of volt meters, ammeters, single and polyphase watt meters, power factor meters and frequency meters.

This is an ideal condition from both the manufacturing and

FIG. 4,472.—Jewel dynamometer movement with left half of magnetic shield removed.

application points of view when practically one mechanism or movement can be developed and used for such a wide variety of purposes, and for all kinds of applications, throughout the various activities of industry, requiring measurements of electrical quantities.

NOTE.—*In dynamometer instruments* used for watt meters the stationary coils are wound for current, and the movable coils for voltage. The current is conducted to the moving coil through controlling springs. The pointer is assembled a few degrees ahead of the moving coil, so as to give as unform scale divisions as is possible. The slight expansion of the scale near the center is an advantage, as it gives better indications at the more important working loads.

TEST QUESTIONS

1. *What is a dynamometer?*
2. *Describe the fixed and movable coils.*
3. *How is a movable coil suspended?*
4. *What happens when current is passed through both coils?*
5. *How is the current strength measured by a dynamometer?*
6. *How should the instrument be arranged when measuring watts?*
7. *For what kind of measurement is the dynamometer movement especially adapted?*
8. *Describe Siemens' dynamometer.*
9. *Should magnetic material be used in the construction of a dynamometer?*

CHAPTER 84

A. C. Watt Hour Meters

By definition, a watt hour meter is a *watt meter that will register the watt hours expended during a period of time.*

Watt hour meters are often erroneously called **recording** *or* **integrating** *watt meters.*

A watt hour meter consists essentially of: 1, *a motor, the speed of the* **rotating element** *of which is proportional to the power to be measured, and* 2, *a* **registering mechanism** *connecte thereto by suitable gearing.*

There are several types of *a.c.* watt hour meter, which ma be classified as

1. Induction type;
2. Faraday disc type.

Ques. What are the essential parts of a watt hour meter?

Ans. A motor, generator, and counting mechanism.

Ques. What is the function of the motor?

NOTE.—***Meter inaccuracy*** *always means loss to the central station.* If a meter run slow, it causes a direct loss of income, if it run fast, it will make a dissatisfied customer and result in loss of his good will and confidence, and in both cases it will cost money to readjust the meter to accuracy and maintain it. It might be well to point out that the general tendency of meters is to run slow rather than fast, which is at variance with the opinion of the general public.

Ans. Since the motor runs at a speed proportional to the energy passing through the circuit, it drives the counting mechanism at the proper speed to indicate the amount of energy consumed.

Ques. What is the object of the generator?

Ans. It furnishes a suitable counter torque or load for the motor.

Ques. Is there any other resistance to be overcome by the motor?

Ans. It must overcome the friction of all the moving parts.

Ques. Is the friction constant?

Ans. No.

Ques. What provision is made to correct the error due to friction?

Ans. The meter is compensated by exciting an adjustable auxiliary field from the shunt or pressure circuit.

Ques. What is the construction of the generator?

Ans. In nearly all meters it consists of a copper or aluminum disc carried on the same shaft with the motor and rotated in a magnetic field of constant value.

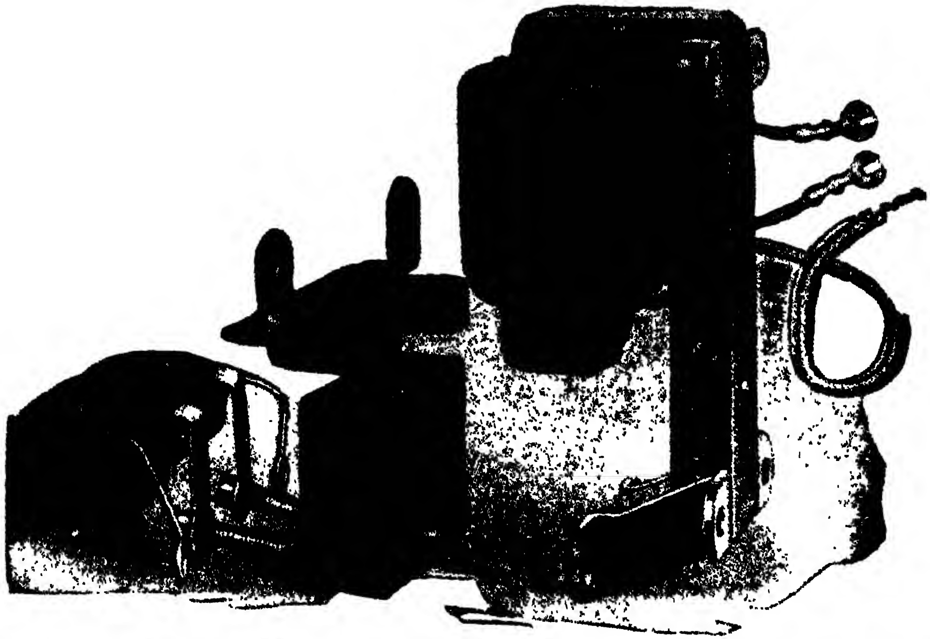
Ques. How is the counter torque produced?

Ans. When the disc is rotated in the magnetic field, eddy currents are induced in the disc in a direction to oppose the motion which produces them.

Ques. What meter is chiefly used on *a.c.* circuits?

Ans. The induction meter.

How a Single Phase Induction Watt Hour Meter Works.—As is well known, the induction meter is simply a highly specialized type of split phase induction motor driving an eddy cur-



FIGS. 4,473 to 4,475.—Disassembled view of electro-magnetic structure of Sangamo single phase induction watt hour meter.

rent generator, the parts being so proportioned and disposed as to produce rotation at a speed in direct ratio to the power passing in the circuit; that is, each revolution corresponds to a definite quantity of electric energy which is totaled on a revolution counter, calibrated to read directly in energy units.

Various makes of induction watt hour meters differ somewhat as to arrangement and construction of the working parts, but the principles involved are practically the same in all.

The eddy current generated has a permanent magnet field and the motor an electro-magnetic field.

There are three principal torques:

1. The propelling torque of the motor element;
2. The retarding torque of the generator;
3. The retarding torque due to friction.

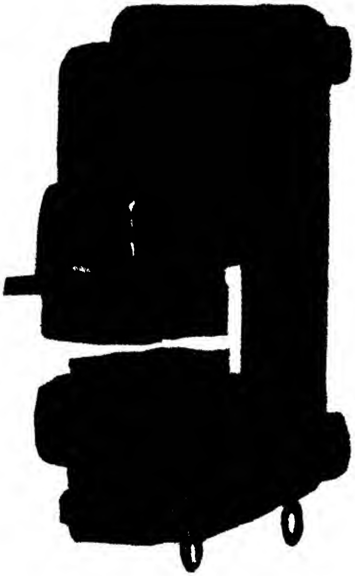


Fig. 4,476.—Assembled view of electro-magnetic structure of Sangamo single phase watt hour meter.

The torque of the motor element is *always proportional to the true watts delivered to the load.*

The retarding torque of the generator *varies directly with the speed of the disc.*

The retarding torque of friction is *the same for all speeds* (this will be understood readily by comparison with the well known Prony brake).

The propelling torque for any speed is of course equal and opposite to the sum of the two retarding torques.

The motor element has two windings.

One of them, known as the current coil, is connected in series with the load, and the other known as the voltage coil, is connected across the line and since it has a high impedance, carries a current proportional to the voltage of the circuit.

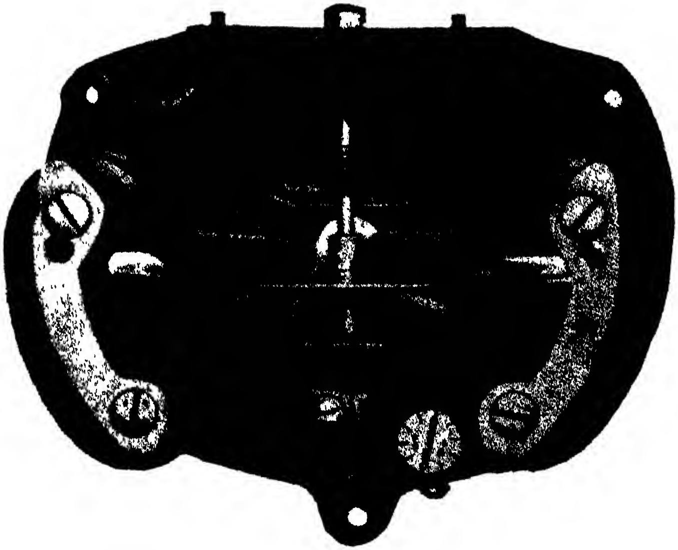


FIG. 4,477.—Sangamo single phase inductive watt hour meter *grid*. The main grid carries the moving system, the permanent magnets, the register and the adjustments. It is of cast iron, in one piece, and accurately machined so as to provide definite and permanent location for all the various parts that are attached thereto, and these in turn are located in definite position to the motor magnet system by the mounting of the grid upon three posts cast in the base. The base of the grid is solid, and taken together with the base of the meter proper, forms a practically continuous magnetic shield around the motor magnets, thus protecting the permanent magnets from any demagnetizing field that may be set up by short circuit currents through the series coils. The full load and light load adjustments are located at the bottom of the grid and are accessible from the front. *In assembling*, the permanent magnets go in first and are clamped down solid on the two brass posts provided in the grid near the tip of the shunt magnet; then the moving system with its bearings and finally the register are inserted.

The split phase effect is secured by winding the current coil with very few turns, so that it is virtually non-inductive, and by winding the voltage coil with a large number of turns and supplying it with a magnetic circuit of low reluctance, thus creating a circuit of high reactance.

As a result the current in the voltage coil is made to lag almost 90° behind the impressed voltage.

The voltage coil with its core is referred to commonly as the "voltage electro-magnet" and the current coil with its core as the "current electro-magnet."

In order to make the flux from the voltage electro-magnet lag exactly 90° behind the flux from the current electro-magnet when the power factor of the load is 1.0, an inductive load adjustment plate is used, as will be explained later on. Reference to fig. 4,481 will show that these two fluxes are constantly changing in direction and magnitude, but that at all times the flux from the voltage electro-magnet lags exactly 90°

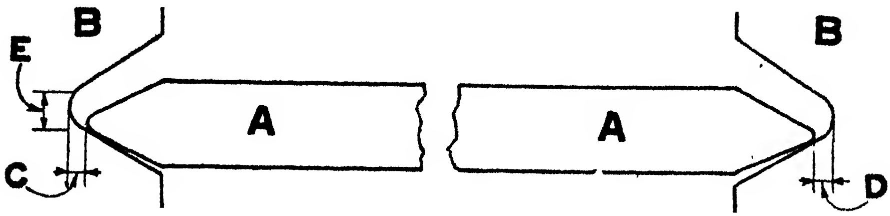
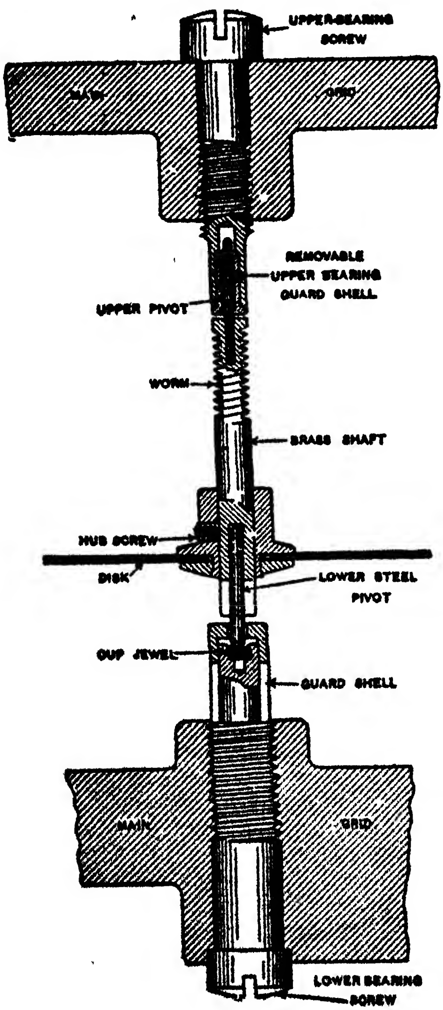


FIG. 4,478.—Instrument shaft illustrating *end play* and *side play*. In the exaggerated view A, is the shaft with glasshard, pointed ends and sapphire jewels B and B. The total distance C+D, that the shaft can move from end to end is called the *end play* and the distance E, that the pivot can move from one side of the jewels to the other is called the *side play*. End play and side play are usually only a few thousandths of an inch and upon the correctness of this detail depends much of the success of the instrument. An important rule of instrument repairing is: *never screw the jewel screws in until they clamp or pinch the moving element;* even once may ruin the pivots. Correctly designed jewels and pivots, usually, require adjustment of only "side play" which is done as follows: Lay the instrument on its back and grasping the pointer gently but firmly with either tweezers or thumb and finger, wiggle it gently back and forth, meanwhile tightening the jewel screw with a screw driver a fraction of a turn at a time until it wiggles only a few thousandths of an inch (about the width of a paper) and then holding the driver firmly, but not pressing down, tighten the jewel lock nut with a suitable wrench.

behind the flux from the current electro-magnet providing the power factor of the load is unity. Each of these fluxes sets up eddy currents in the disc of the meter and these eddy currents in turn produce fluxes of their own which interact with the main fluxes in such a way as to produce a driving torque directly proportional to the product of volts times amperes times power factor; in other words, a torque exactly proportional to the true watts delivered to the load.

The arrangement of the poles is quite different from the arrangement in an ordinary split phase or two phase motor, but the underlying principles are the same.

The flux from the permanent magnet acts as the field of the short circuited generator and the disc serves as its rotating armature. As the disc revolves below the poles of the permanent magnet, cutting the lines of force emanating therefrom, eddy currents (often referred to as Foucault currents) are set up in the disc and these in turn set up a flux of their own which interacts with the flux from the permanent magnet (in accordance with Lenz' law) to retard the motion of the disc.



The retarding torque so developed varies directly with the speed of rotation.

The power absorbed by this short circuited generator, which functions as a magnetic brake, must be sufficient to hold the speed at a fairly low value in order to prevent undue wear of moving parts and also in order to avoid a certain retarding

FIG. 4,479.—Sangamo single phase inductive watt hour meter *bearing system*. The *upper pivot, or bearing* is made of tempered steel wire and of sufficiently small diameter to be quite flexible in the length between the top of the brass shaft and the guide ring in which it rotates. The guide ring, made of phosphor bronze, has the bearing hole burnished. The upper bearing screw, in which the bronze bushing is carried, is so constructed that a long brass sleeve closely surrounds the upper pivot of the spindle. Any blow against the moving system, caused by accident or short circuit, will slightly deflect the shaft until the steel pivot touches against the side of the shell, thus preventing danger of breaking off or bending the upper pivot. At the same time a cushioning or flexible action between the shaft and the bearing shell is secured, thus eliminating the effect of vibration in the moving system, which would tend to produce rattling. *The lower bearing* consists of a cup sapphire jewel, supported in a threaded pillar, the upper end of which is provided with a sleeve so located that it prevents the moving element dropping out during shipment. This protecting sleeve is held friction tight on the shaft and can be removed if it be desired to inspect the jewel.

torque, due to the interaction between the electro-magnets and the disc, which would be felt if the speed were high.

In addition to holding the speed at a low value the short circuited generator or magnetic brake serves to regulate the speed by means of the full load adjustment.

Since friction torque does not vary with the speed and increases as the bearings become worn, it is not desirable as a retarding torque. Nevertheless, it can be entirely compensated for as long as the character of

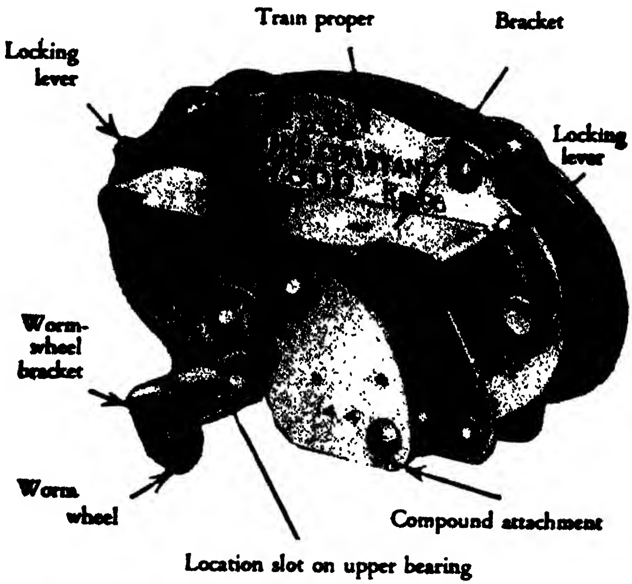


FIG. 4,480.—Sangamo single phase inductive watt hour meter *register;* back view showing arrangement of the worm wheel, compound attachment, locating bracket, and locking levers. *It is located* on a brass bracket and held by two small levers. By drawing the levers down to a horizontal position, they are disengaged from the supporting bracket and the train can be removed by sliding it forward. The bracket is accurately located by two dowel pins set in the top face of the main grid, and is held to the grid by two screws easily accessible from the top. All registers used are marked with symbols on the back of the train and on the compound attachment to indicate the correct register ratio of each combination; this ratio being different for meters of different capacities, in order to obtain a direct reading in kilowatt hours on the dial.

the bearing surfaces remains unchanged. This is accomplished through the agency of the light load adjustment plate. Unfortunately, the condition of the bearing surfaces tends to change from time to time, and it is this that makes the presence of friction so objectionable and which makes it necessary to keep friction torque at a very low value in proportion to driving torque.

Since friction in the lower bearing is proportional to the weight of the moving element it will be apparent that this part should be made as light as is consistent with necessary strength and that the driving torque should be kept at a high value, also that a meter with a high torque will not give satisfactory long time operation if in addition to high torque it has a heavy moving element. This is especially true of induction type meters, for in addition to the wear due to turning friction, there is the wear due to the ceaseless vibratory motion of the moving element which is not present in *d.c.* meters.

Induction Watt Hour Meter Adjustments.—There are three adjustments:

1. The full load adjustment;
2. The light load adjustment;
3. The inductive load adjustment.

The full load adjustment regulates the retarding torque of the short-circuited generator; the *light load adjustment* is a device for exactly counter-balancing friction torque, and the *inductive load adjustment* influences the driving torque of the motor element on inductive loads.

In the Duncan induction watt hour meter:

1. *The full load adjustment* is made by raising and lowering the full load adjustment screw. As the head of this screw is moved upward toward the poles of the permanent magnet (its front turned to the right) more flux is made to cut the disc and as a result the braking effect of the short circuited generator is increased and the speed of the meter reduced. As the head of this screw is moved away from the poles of the permanent magnet the opposite result will be observed.

2. *The light load adjustment* device consists of two hollow squares, each of which surrounds one of the poles of the voltage electro-magnet. If this plate be placed symmetrically with respect to the two poles of the voltage electro-magnet it will have no effect whatever upon the operation of the meter at light load, but as this plate is moved to the right or to the left out of symmetry with the poles of the voltage electro-magnet the meter will be given a slightly forward or backward torque. This plate has the effect of setting up slightly shifting magnetic fields which have a constant influence upon the disc at all meter speeds, so that any given friction torque can be exactly compensated.

3. ***The inductive load adjustment*** plate is similar to the light load adjustment plate except that it is intended to be symmetrically placed with respect to the poles of the voltage electro-magnet at all times, and, therefore, has no influence upon the light load operation of the meter.

Instead of moving this plate in a horizontal direction, as is the case with the light load adjustment plate, it is moved vertically and has more effect as it is moved closer to the voltage coils and less effect as it is moved downward away from the voltage coils. The inductive load adjustment plate does not operate in connection with the voltage electro-magnet to produce a shifting magnetic field, but instead simply superimposes a second field upon the main field of the voltage electro-magnet, the two fields

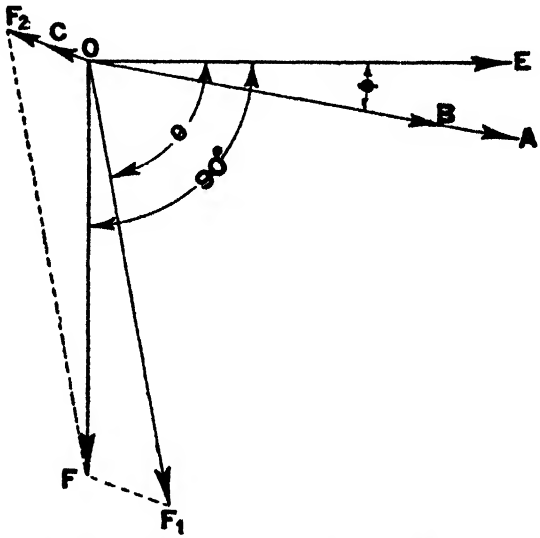


FIG. 4,481.—Diagram showing relation of current and voltage fluxes in Duncan single phase induction meter. In the diagram, OE, represents the voltage of the circuit; OA, the current which lags behind OE, by an angle ϕ; OB, flux of the current electro-magnet which is assumed to be in phase with OA; OF_1, current and flux in the voltage coil which lags behind the voltage of the circuit by an angle θ; OC, current in the inductive load adjustment plate; OF_2, flux produced by this current; OF, represents the resultant of OF_2, and OF_1, and it will be noted that OF, is exactly 90° behind OE. Under these conditions, the meter will have a torque proportional to OE $\times$ OA $\times$ cosine of ϕ. This is proportional to the energy being used.

forming a resultant flux which differs by exactly 90° from the flux set up by the current electro-magnet when the power factor of the load is 1.0. In this way the meter is made to record accurately on loads of all power factors, for the torque of the meter, when it is correctly adjusted for inductive loads, will be exactly proportional to the sine of the angle of

phase difference between the current and voltage fluxes, which is exactly equal to the cosine of the angle by which the current lags behind the voltage of the circuit.

Since the true power delivered to the load is equal to effective amperes times effective volts times the cosine of the angle of lag, it is at once apparent that the torque of the meter will at all times be proportional to the power delivered to the load no matter what the power factor.

Fig. 4,481 is a vector diagram showing how the fluxes from the inductive load adjustment plate interact with the fluxes from the voltage electro-magnet to form a resultant which is exactly 90° from the flux produced by the current electro-magnet when the power factor of the load is unity.

In other words, exact quadrature under these conditions is made to exist between the current and voltage fluxes and as a result the meter will register a load of any power factor whether leading or lagging with high accuracy.

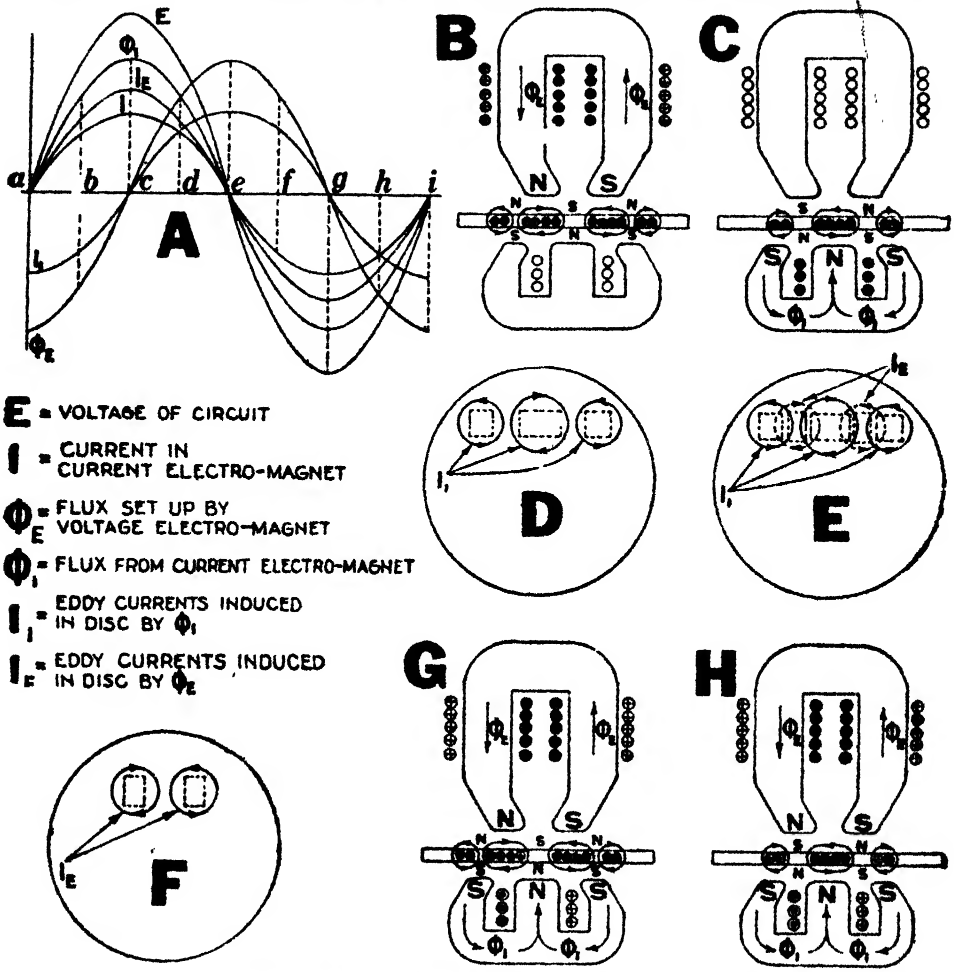
Creeping.—If an induction watt hour meter be correctly adjusted and contain no friction and if the line voltage be steady and no vibration be present, the disc will not start to creep, but if there be a little friction present or if the line voltage be somewhat higher than normal or if the meter be mounted upon a wall where there is vibration, the disc may tend to creep slightly.

In order to prevent continuous creeping, two holes are punched in opposite sides of the meter disc. When one of these holes comes within the influence of the voltage electro-magnet at the rear of the meter, the tendency to creep will be overcome, since the resistance of the disc is increased thereby lessening the forward torque produced by the light load adjustment. Two holes are provided, rather than one, to balance the disc, and to prevent the meter creeping more than one-half of one revolution.

In order to simplify the problem as much as possible, assume a load having a unity power factor.

Curve E, in fig. 4,482, represents the voltage impressed on the voltage electro-magnet and curve ϕ_E, the flux set up by the voltage electro-magnet. Intervals of time are represented on the horizontal line *ai*. This flux is made to lag behind the voltage by exactly 90° due to the high impedance of the voltage electro-magnet and to the inductive load adjustment.

Curve I, represents the current in the current electro-magnet and is of course in phase with E, and also ϕ_1, which is the flux set up by the current I. It will be seen from curves ϕ_E, and ϕ_1, that at instant *a*, the flux



FIGS. 4,482 to 4,489.—Diagrams showing how torque is produced in Model M2 Duncan watt hour meter. A, curves; B, magnetic poles of electro-magnets, also eddy currents in disc developed by current electro-magnet at instant *a*; C, magnetic poles of electro-magnets, also eddy currents in disc developed by voltage electro-magnet at instant *c*; D, eddy currents in disc being developed at instant *a*, by current electro-magnet; E, eddy currents in disc being developed at instant *b*, by both current and voltage electro-magnets; F, eddy currents in disc being developed at instant *c*, by voltage electro-magnet; G, magnetic poles of electro-magnets and eddy currents I at instant *b*; H, magnetic poles of electro-magnets and eddy current I at instant *b*.

in the current electro-magnet is passing through its zero point, changh from negative to positive, and that the flux from the voltage electr magnet is at a negative maximum.

The flux ϕ_1, from the current electro-magnet induces eddy currents in the disc, as I_1. Since the magnitude of the induced current depends upon the rate of flux change, the current I_1, will be at negative maximum when the flux ϕ_1, is on the point of changing from negative to positive. It will also be at a zero value when ϕ_1, is maximum. In other words I_1, lags exactly 90° behind ϕ_1, in time relation and is in phase with ϕ_E, the flux from the voltage electro-magnet. B, represents diagrammatically the relationships at instant *a*. It will be seen that the currents I_1, induced in the disc by ϕ_1, are as indicated in B and D. These eddy currents I_1, set

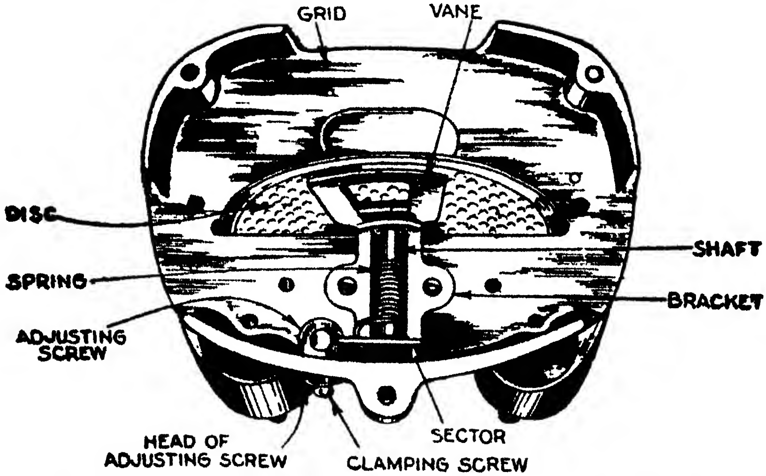
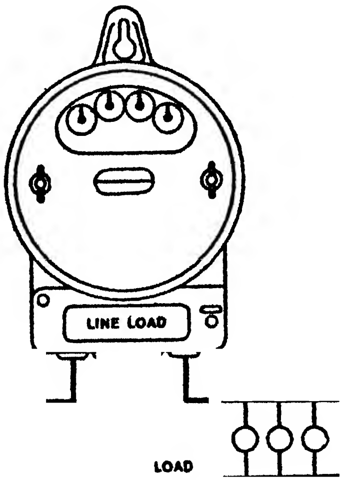


Fig. 4,490.—Sangamo single phase inductive watt hour meter *grid* (back view) showing *light load adjustment*. The principle involved is practically the same as used in all modern types of induction meters. The variation lies simply in the mechanism for manipulating the device. *The device consists of* a vane, or flat single turn shading coil, stamped out of a piece of low resistance metal, located in the gap of the shunt field so that the action of this field produces secondary currents within it. When this vane lies on either side of the center of the field it produces an unbalanced effect which tends to rotate the armature either forward or backward, depending upon which side the vane is placed. *In construction,* the vane is mounted on a shaft carried by a bracket fastened with screws to the back of the grid. On the lower end of the shaft is riveted a sector with teeth milled into its edge. These teeth engage a screw, the head of which is accessible from the front. A coil spring prevents any back lash between the sector and the screw; therefore, the tightening of the clamping screw holds the adjustment permanently as set. The adjusting screw is stamped with ten divisions, and arrows with letters F, and S, that indicate respectively the direction of movement to make the meter run faster or slower on light load. One complete revloution of the adjusting screw produces a change of approximately 2.5% at one tenth load, or one division produces a change of about .25%. Therefore, with slight practice it is not difficult to obtain an adjustment of .1% at on tenth load.

up fields as shown in B, which are in phase with ϕ_E, the flux from the voltage electro-magnet.

The letters N and S, in B, represent the relative positions of the poles of these fields. It will be noted that there will be an attraction between the fields having the same direction, and a repulsion between those having opposite directions. Thus there will be a tendency for that portion of the disc between the electro-magnets to move from right to left so the fields having the same direction will coincide.

Since the back of the disc as in D, is being considered, the direction of rotation in front will be from left to right or "forward" rotation.



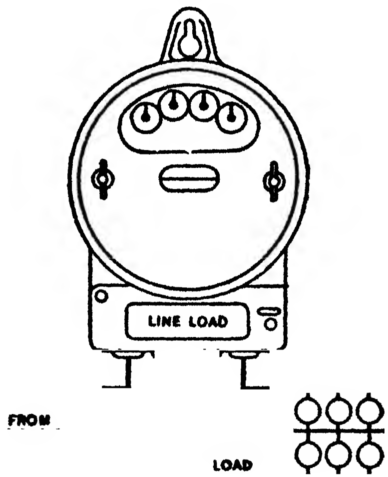


FIG. 4,491.—Sangamo type H single phase watt hour meter. Two wire, capacity 5 to 100 amperes inclusive.

FIG. 4,492.—Connections for Sangamo type H single phase watt hour meter. Three wire, capacity 5 to 100 amperes, inclusive.

In the discussion so far the effect of the eddy currents I_E, induced in the disc by the flux ϕ_E, has not been considered.

Upon referring to A, it will be noted that at instant *a*, these currents are zero.

At instant *c*, the flux ϕ_E, due to the voltage electro-magnet is at its zero point while the flux ϕ_I, from the current electro-magnet is a positive maximum. The action here is similar to that at instant *a*, except that the conditions are reversed.

The flux ϕ_E, from the voltage electro-magnet induces currents in the disc as I_E, which lag ϕ_E, by exactly 90°. At instant *c*, they are a positive maximum. The current I, in the current electro-magnet is at a maximum as is the flux ϕ_1, which it sets up.

Upon referring to C, it will be noted that the center pole of the current electro-magnet is now a north pole and the two outside poles are south. At instant *c*, the eddy currents I_E, in the disc which are set up by the voltage electro-magnet are a maximum and are as shown in C, and F. As in B, the letters N and S, represent the relative positions of the poles

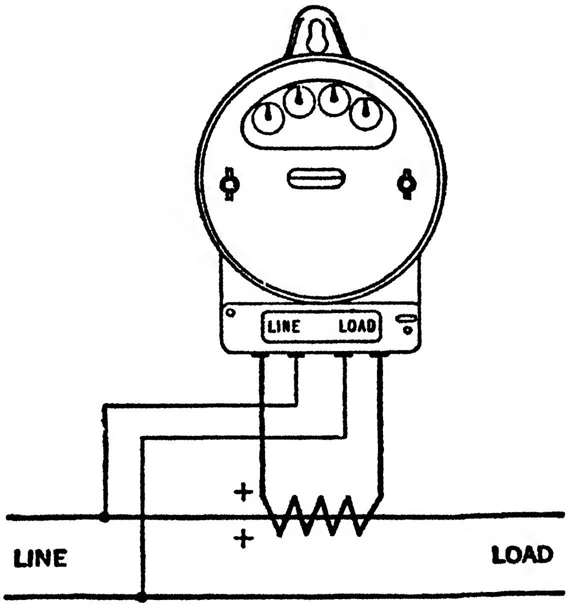


FIG. 4,493.—Connections for Sangamo type H single phase watt hour meter, with current transformer. Two wire, capacity 150 amperes and above.

of the fields set up by the eddy current I_E, in the disc and the fields set up by the flux ϕ_1, from the current electro-magnets.

As before there is an attraction between the fields having the same direction and a repulsion between those having opposite directions so there will again be a tendency for the disc to have "forward rotation."

Thus the direction of motion of the disc at instant c, is the same as at instant a. At instant a, there are no eddy currents generated in the discs by flux ϕ_E, from the potential electro-magnet due to the fact that it is at its maximum value and the rate of flux change is zero.

Likewise at instant c, there are no eddy currents generated in the disc by flux ϕ_1, from the current electro-magnet as it is then at its maximum.

By following this analysis through instants e, g and i, thus completing the cycle, there will be found a tendency to produce forward rotation at each instant.

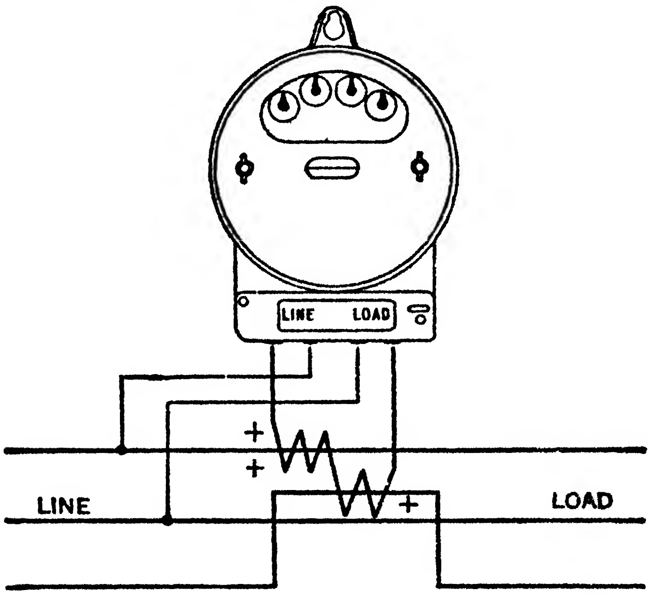


Fig. 4,494.—Connections for Sangamo type H single phase meter with three wire current transformers. Capacity 150 amperes and above.

When considering instants between a, c, e, g and i, such as b, a somewhat more complicated situation arises.

At this instant both current and voltage fluxes are changing rather rapidly. Theoretically it would be possible to combine these fluxes into a resultant, but a study of what happens can best be pursued by first considering the torque producing effect of the poles of the voltage electro-magnet when interacting with the poles in the disc generated by the eddy currents set up by the current electro-magnet, and then seeing the effect

of the interaction of the poles of the current electro-magnet and the poles set up by the eddy currents in the disc resulting from the voltage electro-magnet.

It will help in understanding the situation if attention be called to the fact that the eddy currents, generated by the current electro-magnet, set up poles in the disc which have no torque producing qualities so far as the poles of the current electro-magnet are concerned.

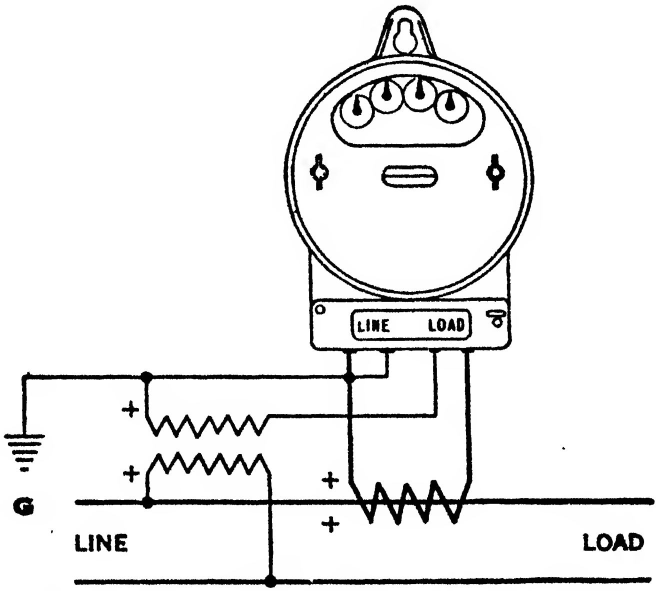


FIG. 4,495.—Connections for Sangamo type H primary meter with current and potential transformers, all capacities.

This is also true of the voltage electro-magnet, except that the light load adjustment plate used in connection with the voltage electro-magnet gives a slightly unbalanced effect which produces a very slight torque, which is just sufficient to overcome friction. For the purpose of the present discussion, however, it may be assumed that the voltage electro-magnet sets up eddy currents in the disc which form magnetic poles and that these magnetic poles when considered in connection with the poles of the voltage electro-magnet do not tend to produce torque. A study of the diagrams will show this point more clearly.

The curves in I, show that the eddy currents I_1, being induced in the disc at instant *b*, are as indicated in E and G. These currents are in the same direction as they were at instant *a*, but are reduced in strength.

Curve ϕ_E, shows the flux from the voltage electro-magnet at instant *b*, to be in the same direction as at instant *a*, but like I_1, reduced in strength. Therefore, the action between the fields set up by the eddy current I_1, which are induced in the disc by the current electro-magnet and the flux ϕ_E, from the voltage electro-magnet is to produce torque as indicated in G, which is similar to B. Since *b*, can represent any point between *a* and *c*, the torque due to these two quantities will vary from a maximum at *a*, to zero at *c*.

At instant *b*, eddy currents I_E, are also being induced in the disc by the flux ϕ_E, from the voltage electro-magnet. These eddy currents have the same direction at instant *b*, as in instant *c*, but have not yet reached their maximum strength. The flux ϕ_1, from the current electro-magnet likewise has the same direction at instant *b*, as at instant *c*, but has not yet reached its maximum value. It has the direction as indicated in H. ϕ_1, and the magnetic fields set up by I_E, interact to produce rotation in the same way and direction as they do at instant *c*.

At instant *b*, is seen, therefore, two torques acting at the same time to produce a forward rotation of the meter disc. This reasoning if followed through the complete cycle will show that the preceding torques combine to produce a pulsating torque tending to drive the disc in a forward direction.

In this discussion no attempt has been made to take into consideration the damping torques arising from the interaction of the fluxes from the current and voltage electro-magnets with the eddy currents which they induce in the disc.

A discussion of them here would not alter the preceding explanation and would only serve to complicate it. Therefore, it is sufficient to say that the disc in cutting through the fluxes from the current and voltage electro-magnets has eddy currents generated in it and these for their amplitude are just as effective in damping the rotation of the disc as those generated from the permanent magnet flux. The result is that the total damping torque in the induction type meter is not constant, but increases as the current in the current coil of the meter increases.

The damping effect of the electro-magnets is an important item to be considered in the design of an induction type watt hour meter as it influences appreciably the characteristics.

Methods of Adjustment.—The following instructions relate in particular to the Duncan meter, although the principles involved are general.

Single Phase Meter

Full Load Adjustment.—This is effected by means of a large flat headed screw M, as shown in fig. 4,496, situated immediately below the poles of the permanent magnet.

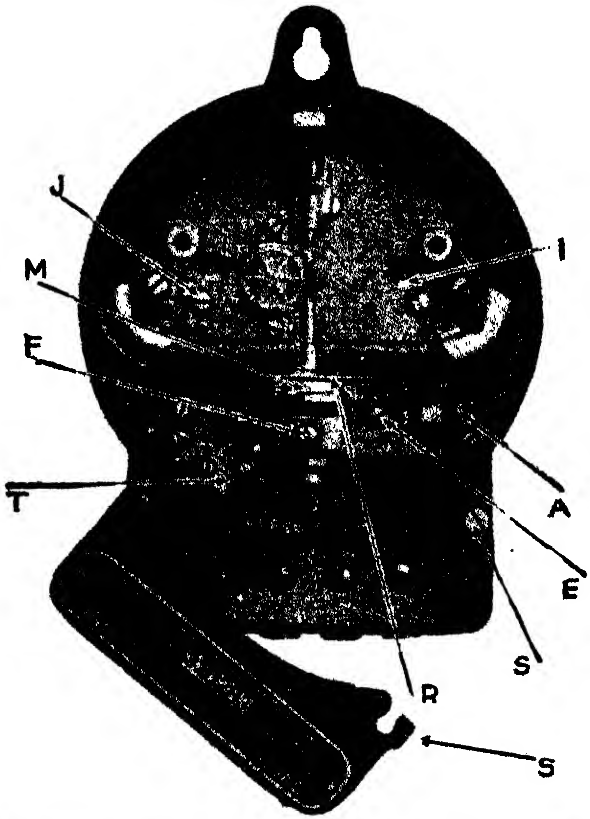


FIG. 4,496.—Duncan single phase induction watt hour meter with register removed. *The parts are:* A, light load adjustment screw; E, light load adjustment clamp screw; S, terminal chamber cover sealing screw; S, sealing ear on terminal chamber cover; R, disc; T, test link; F, full load adjustment clamp screw; M, full load adjustment screw; J, inductive load adjustment clamp screw; I, inductive load adjustment.

Turning the front of this screw to the right will cause the meter to run slowly on full load and turning it to the left will cause the meter to run faster on full load. In meters of recent manufacture, this is clearly indicated by two arrows and by the letters F, and S. The direction is the same for all Duncan single phase meters.

Before turning the full load adjustment screw, the clamp screw F, must be loosened, and of course, this should be tightened after adjustment has been made and before making the test runs.

Light Load Adjustment.—This, like the full load adjustment, is of the micrometer type and is made by turning the light load

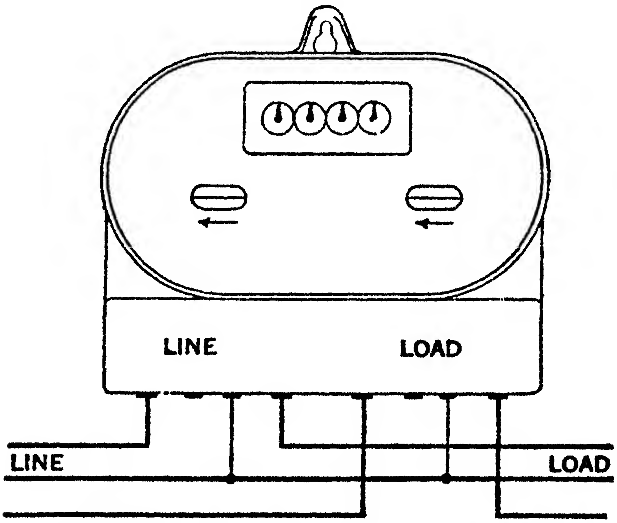


FIG. 4,497.—Connections for Sangamo type H horizontal polyphase meter, two and three phase, three wire.

adjustment screw A, so as to cause the light load adjustment plate to move to the right or left.

Turning this screw so that its front is moved upward will cause the meter to run faster at light load and turning it so that the front moves downward will bring about the opposite result. In meters of recent manufacture, the head of this screw is marked with two arrows and with the letters F, and S, so that it is not necessary for the meter tester to remember which way to turn this screw. In older types of meters, the

direction of rotation is shown by an instruction sheet pasted to the inside of the meter cover. Before attempting to turn the light load adjustment screw, the light load adjustment clamp screws EE, should be loosened and should be tightened again after turning screw A, and before making further tests.

Meters made at the present time are provided with a spring to take up back lash. The purpose of this spring may be defeated if the light load adjustment screw be moved while the clamp screws are tight.

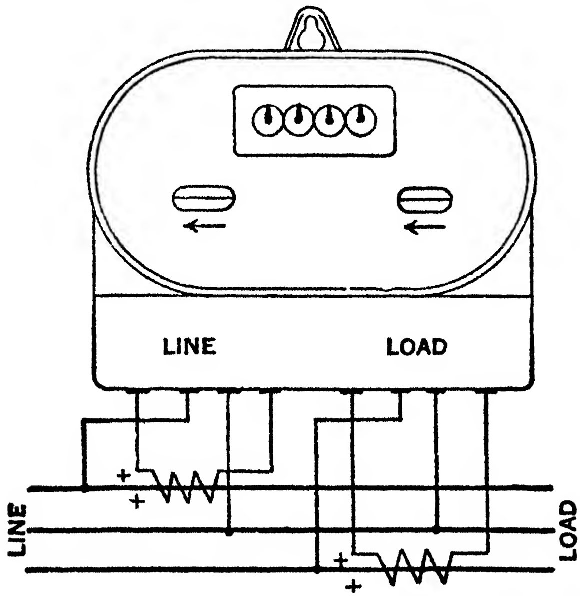


FIG. 4,498.—Connections for Sangamo type H horizontal polyphase meter, two and three phase, three wire, with current transformers.

Inductive Load Adjustment.—This will seldom require attention, as it is carefully set at the factory. When adjustment is necessary, first loosen the inductive load adjustment clamp screws JJ, which should be tightened again immediately after changing the adjustment and before test runs are made.

Raising the ears B, will cause the meter to run faster on inductive loads and lowering them will cause the meter to run slower on such loads. It is best to keep the two ears exactly level with each other. If one of them

be higher than the other, the light load adjustment of the meter will be affected to some extent.

Polyphase Meter

Full Load Adjustment.—Although the polyphase meter is provided with two full load adjustment screws, one of them will usually suffice, and the screw G, is the only one indicated in fig. 4,500. The adjustment is exactly the same as in the

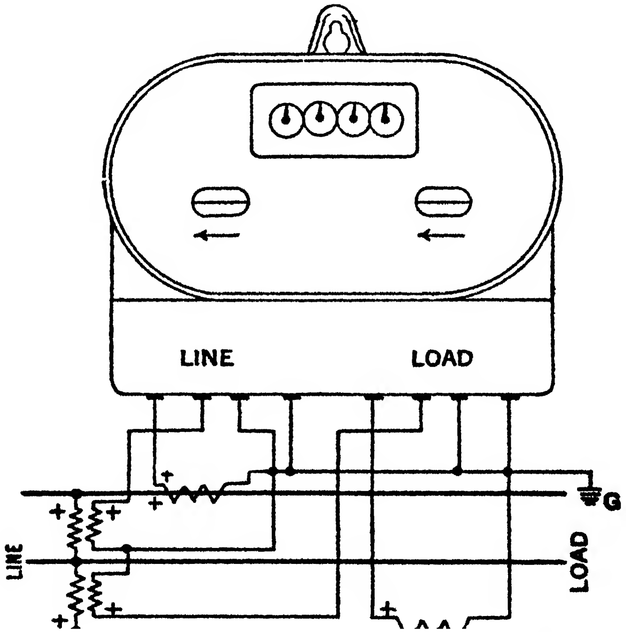


FIG. 4,499.—Connections for Sangamo type H horizontal polyphase meter, two and three phase, three wire, with current and potential transformers.

case of the single phase meter, and the clamp screw F, should be loosened before each adjustment and tightened after each adjustment.

If the front of the screw be turned to the right, the meter will run slower on full load, and if turned to the left, will run faster on this load.

If the lower full load adjustment screw be used, then its front should

be turned to the left to retard the motion of the discs and to the right to speed up the discs. Both of these adjustments are indicated in meters of recent manufacture by arrows and the letters F and S.

Light Load Adjustment.—Each of the two light load adjustments is locked by two clamp screws. One of the upper clamp screws is shown at E. The clamp screws should be loosened before each adjustment and tightened immediately after each adjustment and before making test runs.

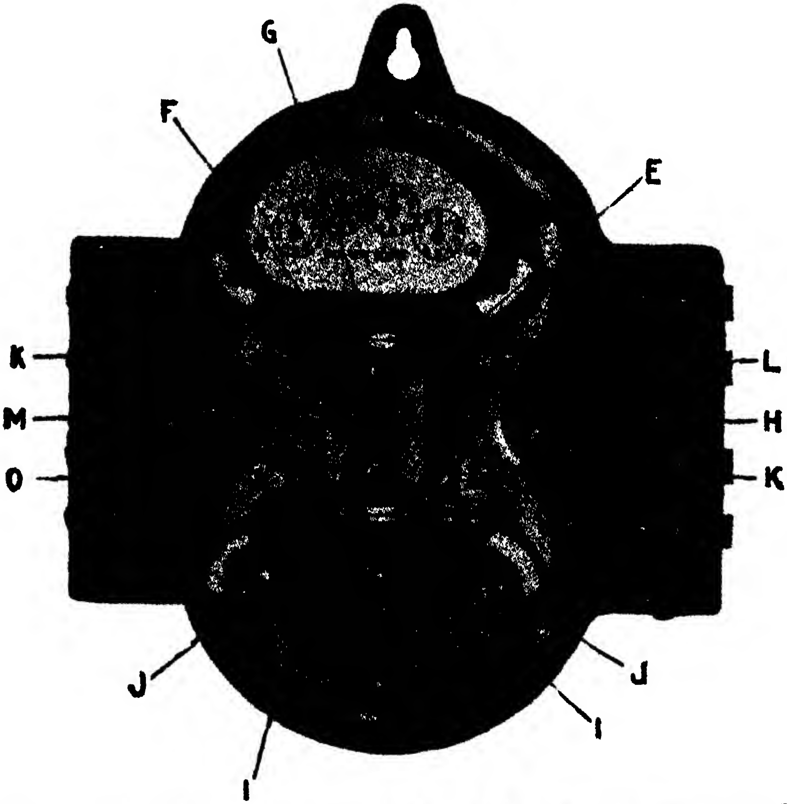
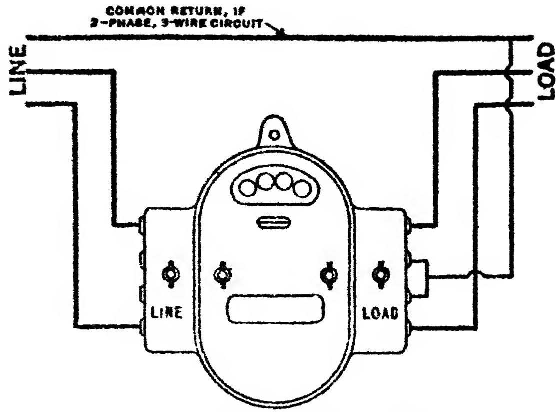


FIG. 4,300.—Duncan polyphase induction watt hour meter. *The parts are:* L and O, light load adjustment screws; E, upper light load adjustment clamp screw; KK, balance adjustment clamp screws: H, balance adjustment screw; F, full load adjustment clamp screw; G, full load adjustment clamp; G, full load adjustment screw; JJ, inductive load adjustment clamp screws for lower element; II, inductive load adjustment for lower element; M, holding screw for dowelled full load adjustment screw plate.



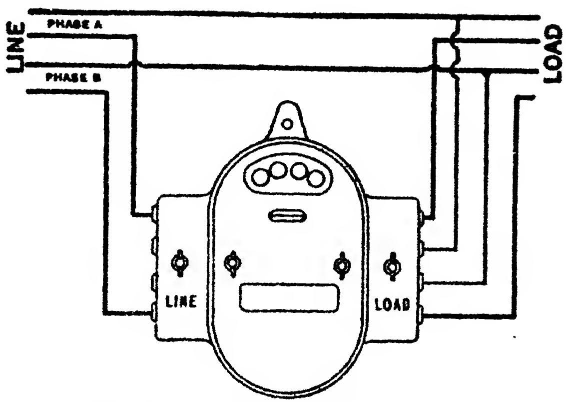


Fig. 4,501.—Connections for Sangamo type H vertical polyphase meter, 5 to 100 amperes, 110 to 550 volts, inclusive; two and three phase, three wire.

Fig. 4,502.—Connections for Sangamo type H vertical polyphase meter, 5 to 100 amperes, 110 to 550 volts, inclusive; two phase four wire.

The upper light load adjustment screw is indicated by the letter L, and the lower by the letter O.

Turning the front of either screw upward will cause the meter to run faster at light load and turning the front of either downward will bring about the opposite result.

Inductive Load Adjustment.—This adjustment on both elements is carefully made at the factory and should not be changed until careful tests prove this necessary. Inductive load tests should be made upon each of the elements at full ampere load and at 50% lagging power factor.

To increase the torque of the lower element at 50 per cent lagging power factor, loosen the clamp screw

JJ, and lower the ears II, approximately the same distance, after which, and before the next test, the clamp screws should be tightened.

Raising the ears II, will reduce the lower element torque at 50 per cent lagging power factor. The inductive load adjustment of the upper element is identical except that its ears should be raised to increase the torque of the upper element at 50 per cent lagging power factor and lowered to secure the opposite result.

Balance of Elements Adjustment.--Loosen screws KK, and

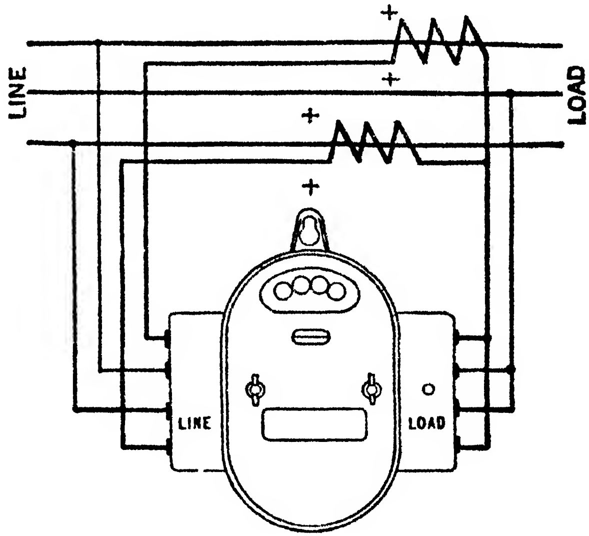


FIG. 4,503.—Connections for Sangamo type H vertical polyphase meter, 150 amperes and over, 110 to 550 volts, inclusive, two and three phase, with current transformers.

turn screw H, until desired result is obtained. Screw H, acts as an eccentric to raise and lower the plate upon which the upper current electro-magnet is mounted, the direction of movement being indicated by the motion of the screws KK, which are mounted on the plate.

Be sure to tighten screws KK, after turning screw H, and before again testing for accuracy. As the screws KK, move upward the upper element will have more and more torque. Turning the screw H, so that the screws KK, come downward will give the upper element less torque. The

balance adjustment is carefully made at the factory and will seldom require attention.

The Registering Mechanism.—This comprises the *dials, pointers, and gear train necessary to secure the required reduction in speed.* This gear train is driven directly by the rotating element and therefore its friction should be low and constant.

The object of the registering mechanism is to register either the revolutions of the rotating element of the motor or the equivalent of those revolutions in kilowatt hours.

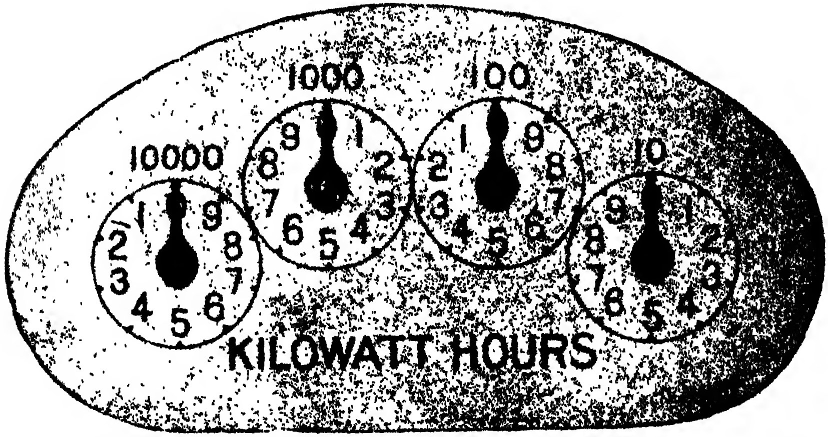


FIG. 4,504.—Sangamo single phase inductive watt hour meter ***register dial.*** The dial circles read 10, 100, 1,000, and 10,000 kilowatt hours from right to left.

In some of the earlier types of meters this mechanism or register was alike for all ratings and such that 1,000 revolutions of the rotating element would cause the first dial pointer to make one complete revolution. The register constant for watt hours for this type of register was the same as the watt hour test constant of the meter.

In other types of meters, additional reduction gearing was introduced into the register so that the register read directly in watt hours, or the register constant was 10 or some multiple thereof. The first type of register has the advantage that with the exception of the register constant, registers for all ratings of meters are exactly alike, and therefore the possibility of a wrong gear ratio was avoided.

The simplicity of the *direct reading* type from a reading and billing standpoint, however, has led to its standardization. The number of revolutions of the rotating element of the meter per kilowatt hour is inversely proportional to the watt hour constant of the meter. Accordingly, the gear mechanism between the rotating element of the meter and the first dial pointer will be different for meters having different test constants.

Furthermore, since watt hour meters are usually read but once each month, the register must be such that it will not repeat (that is, the pointer of the last dial will not pass over the zero on the last dial more than once) during that interval. The following definitions relating to the registering mechanism should be noted.

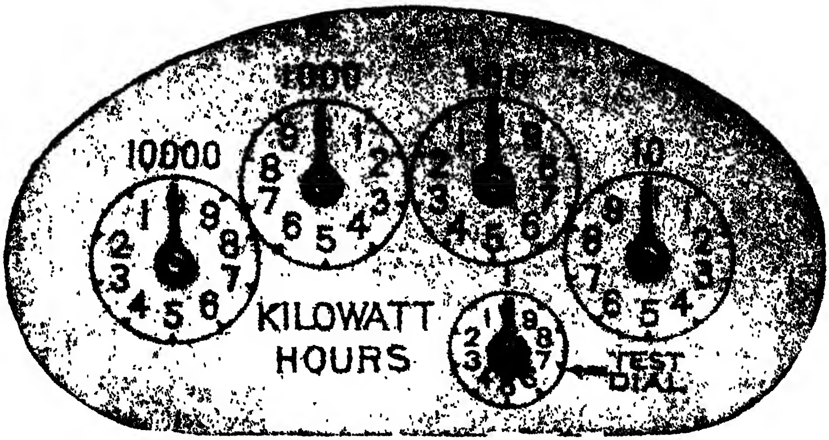


FIG. 4,505.—Sangamo single phase inductive watt hour meter ***register dial*** with ***test dial.*** It has a small test circle indicating one kilowatt hour per revolution in all sizes where the first regular circle indicates 10. This is provided to conform with the requirements of the Canadian Government and it is intended that the hand on the test circle shall make not less than ½ revolution in one hour with full load on a meter.

Definitions

Dials.—The graduated circles over which the dial pointers move.

Dial Pointers.—Those parts of the register which move over the dials and point to the numbers on the divisions of the dials.

Dial Train.—All the gear wheels and pinions used to interconnect the dial pointers.

First Dial.—The graduated circle over which the most rapidly moving dial pointer moves, the test dial not being considered.

Gear Ratio.—(R_g) The number of revolutions of the rotating element for one revolution of the first dial pointer.

Register.—That part of the meter which registers the revolutions of the rotating element or the equivalent of those revolutions in kilowatt hours.

Register Constant.—(K_r) The factor used in conjunction with the register reading in order to ascertain the total amount of electrical energy in the desired unit, that has passed through the meter.

Register Ratio.—(R_r) The number of revolutions of the wheel meshing with the worm or pinion on the rotating element for one revolution of the first dial pointer.

Register Reading.—The numerical value indicated on the dials by the dial pointers. Neither the *register constant*, nor the test dial, if any exist, is considered. On some meters a multiplier (such as 100s) is printed adjacent to the dial to which it applies; on others a number adjacent to the dial (printed without the letter s) is the numerical value of one revolution of that dial hand. Such multipliers or adjacent numbers also are disregarded when recording the *register reading*. On some meters the first dial has its major divisions marked with two digit numbers; its indication should be so recorded. The matter of register readings is greatly simplified, and the errors of meter readers are minimized, when standard registers are used.

Registration.—The numerical quantity expressed in the desired unit corresponding in value to the energy that has passed through the meter. It is equal to the product of the register reading and the register constant. The registration during a given period of time is equal to the product of the register constant and the difference between the register readings at the beginning and the end of the period.

Standard Register.—One in which each of the four dials is divided into ten equal parts, the division marks being numbered from zero to nine and the gearing between the dial pointers is such that the relative movements of adjacent dial pointers are in opposite directions and in a 10 to 1 ratio. The *constant* necessary for use in conjunction with the register reading may be 1, 10 or any power of 10. Nothing appears on the register face in addition to the dials except the word *kilowatt hours* and the *register constant*.

Test Dial.—An extra dial placed upon the register face, or other part of the register, of some meters and used only when testing the meter. The term *test dial* does not apply to any of the dials on a rotating standard.

The *gear ratio, register ratio and register constant* (see definitions) are important factors in the correct registration of the meter.*

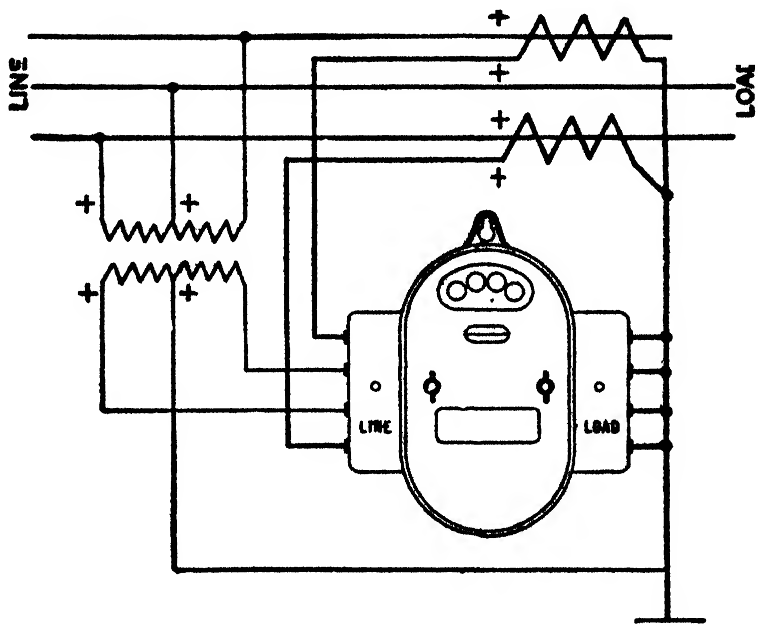


FIG. 4,506.—Connections for Sangamo type H vertical polyphase meter, all capacities, 1,100 volts and above, two and three phase with current and potential transformers.

When the dial train is removed, the gear wheel, which meshes with the worm or pinion on the rotating element shaft, remains in the meter. It should be noted in such cases that

*NOTE.—Practically all manufacturers have adopted the various recommendations of the different Meter Committees and at the present time mark the value of the register ratio on the back plate of the register.

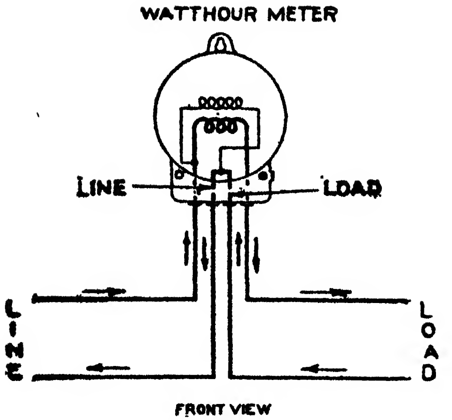
the gear ratio and register ratio includes as much of this gearing left in the meter, as would be included were it integral with the part of register removed from the meter.

A worm and worm wheel are frequently used in connection with gears for speed reduction. A single worm is simply a screw thread on a shaft and in a train of gears acts similarly to a gear having but one tooth. The worm is arranged so as to engage a worm wheel having a relatively large number of teeth.

FIG. 4,507.—Westinghouse polyphase watt meter with cover and dial removed.

A double worm is sometimes employed, consisting of two screw threads on a shaft, which acts as a gear with two teeth. In calculations a single worm should be considered as a gear having one tooth, and a double worm as a gear having two teeth.

A worm and worm wheel require less space than a pinion and gear designed for the same conditions, and involve a 90° difference in direction between the axes of rotation of the worm and the gear.



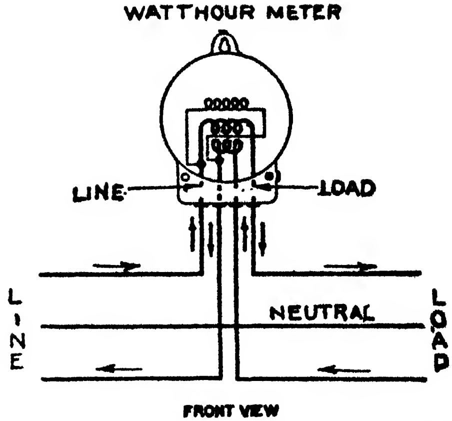
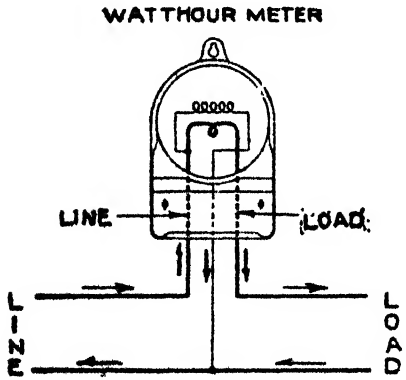


FIG. 4,508.—Connections of 2 wire Duncan model M2 watt hour meter, 5 to 100 amperes, 600 volts and less.

FIG. 4,509.—Connections of 3 wire Duncan model M2 watt hour meter, 5 to 150 amperes, 600 volts and less.



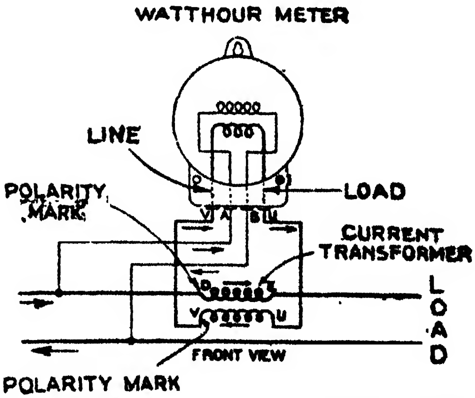


FIG. 4,510.—Connections of 2 wire Duncan model M2 watt hour meter, 150 to 300 amperes, 600 volts and less.

FIG. 4,511.—Connections of 2 wire Duncan model M2 watt hour meter with current transformer, 400 amperes and above, 600 volts and less.

TEST QUESTIONS

1. *What is a watt hour meter?*
2. *Of what does a watt hour meter consist?*
3. *Name two types of watt hour meters.*
4. *How does a watt hour meter work?*
5. *What is the object of the motor and the generator?*
6. *What provision is made to correct the error due to friction?*
7. *What meter is chiefly used on a.c. circuits?*
8. *Describe the operation of a single phase induction watt hour meter.*
9. *Describe the three principal torques.*
10. *How is the necessary split phase effect secured?*
11. *Name three adjustments for watt hour meters.*
12. *How is the full load adjustment made?*
13. *Describe the light load adjustment device.*
14. *How is the inductive load adjustment made?*
15. *What i creeping?*
16. *How is creeping prevented?*
17. *How are adjustments made on the polyphase meter?*
18. *Describe the balance of elements adjustment.*
19. *Of what does the registering mechanism consist?*
20. *What is the object of the registering mechanism?*
21. *Name two types of registering mechanism.*
22. *Give a list of terms relating to registering mechanism and define them.*
23. *Name some important factors in the correct registration of the meter.*

CHAPTER 85

Demand Meters

By definition a demand meter is ***a device which indicates or records the demand or maximum demand.***

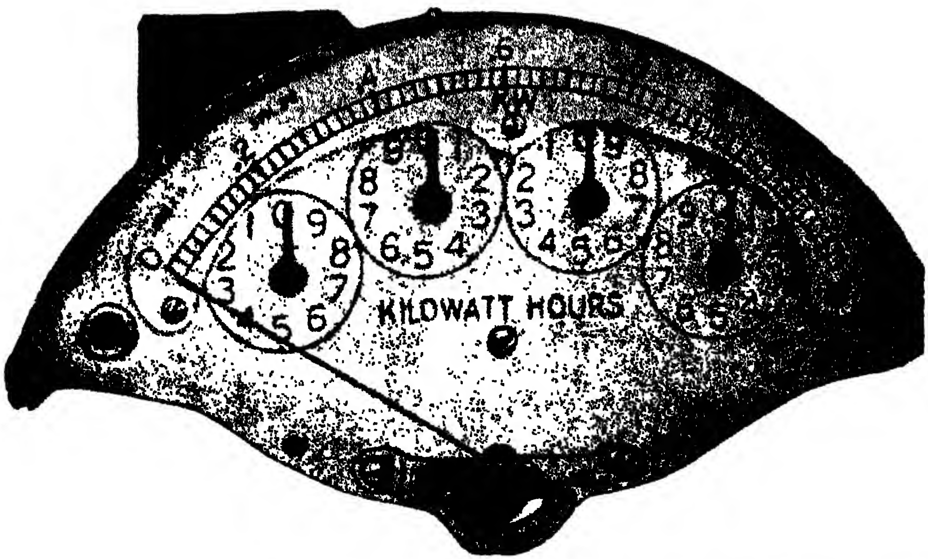


Fig. 4,512.—General Electric demand watt hour meter register. Scale shown is for 5 ampere, 110 volt, 3 wire, 3 phase meter.

The majority of central stations now include in their tariffs, some form of demand rate requiring the use of demand meters.

A demand rate is ***one in which a factor is introduced offering certain economies to a customer who will arrange his draft of energy so as to require a steady non-fluctuating supply over the major part of the working period.***

It is easily understood that such a load is of great benefit to the central station as it reduces the amount of generating and line equipment necessary to supply the abnormal peaks which might otherwise occur. The benefit of reduction of fixed charges on the central station is passed on to the customer who aids, by his load regulation, in reducing them, and conversely a customer whose power requirements vary considerably, bears a proportional share of the expense incurred by the company in keeping equipment ready to meet such fluctuations.

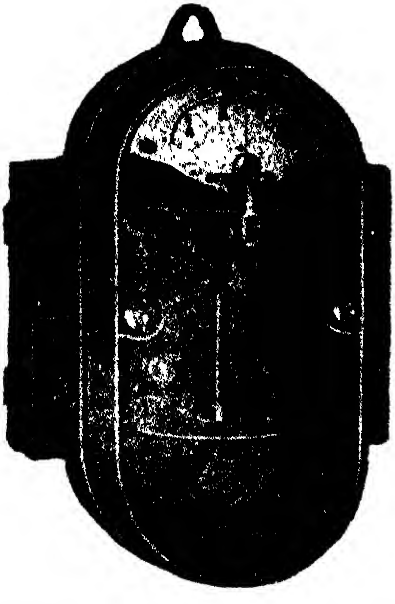


FIG. 4,513.—General Electric single phase watt hour demand meter.

FIG. 4,514.—General Electric polyphase watt hour demand meter.

The usual form of charge for maximum demand or "stand by service" as sometimes termed in rate discussions, is a definite rate per kilowatt or kilovolt ampere of maximum demand as determined by demand meters, while the kilowatt hours of actual energy used are measured in the usual way by watt hour meters, and sold separately at a fixed schedule, both items of charge being included in the gross bill. For this reason it is necessary to provide distinct elements to indicate or record kilowatts and kilowatt hours separately, although the individual elements may be and often are combined in one case, and sold as one meter.

Demand meters *measure a quantity which is composed of an electrical factor and a time factor.*

Accordingly each demand meter must contain an electrical element and a timing element which may be structurally either distinct or combined with each other. These two elements combined with a suitable recording or indicating element make up the demand meter.

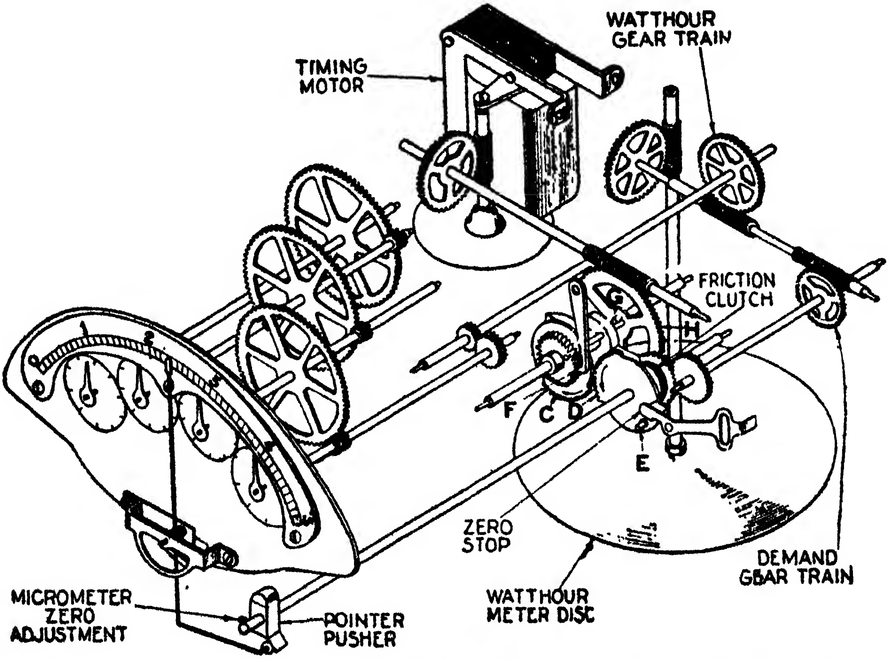


FIG. 4,515.—Diagram of General Electric demand watt hour meter register. ***The meter train*** is driven directly by the meter disc shaft in the usual manner. The demand train is likewise driven directly by this same shaft, but with a disc type of friction clutch interposed between the worm wheel and demand pointer. Both registering elements (watt hour train and demand train) advance together. At the end of each interval, the demand train is reset to zero by the synchronous motor and a counterweight. The resetting operation is practically instantaneous. The motor gradually raises the counterweight to its overbalancing position. It then drops suddenly. In doing so it momentarily engages a mutilated gear on the demand drive shaft carrying it to zero. The force thus applied is sufficient to slip the clutch through which the demand train is driven. This allows the return to take place without disturbing the gearing to the watt hour meter. If for any reason the action of the counterweight fails to return the demand pointer completely to zero, the motor overtakes the counterweight and forcibly drives the demand train to zero. This principle gives to the register its positive reset feature. Thus, an over registration of demand in the ensuing interval cannot occur because of failure to return to zero.

The electrical element of a demand meter is *that portion which is affected by the electrical quantity which it is desired to measure;*

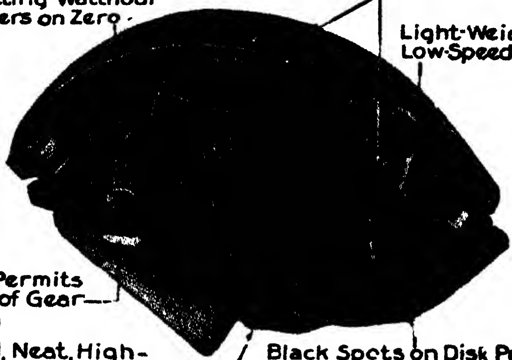


FIG. 4,516.—General Electric watt hour demand meter register; back view.

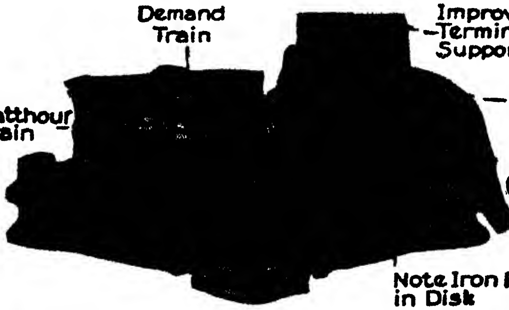


FIG. 4,517.—General Electric watt hour demand meter register mechanism. A synchronous motor establishes the timing. Resetting of the demand mechanism is almost instantaneous. Moreover, its action is positive. The motor follows up the counterweight, and if the latter fail to return it completely, the motor actually drives the mechanism to zero. The power required to restore the advancing mechanism to zero is supplied by the motor. The meter is not required to do this work, and is, therefore, practically unaffected by the additional load or friction from the demand train, also the available power of the motor is utilised efficiently by gradually storing up energy in the counterweight to effect the resetting operation. A micrometer zero adjustment for the demand pointer is provided as well as a means for quickly returning the watt hour pointers to zero.

the magnitude of the effect gives a measure of that electrical quantity.

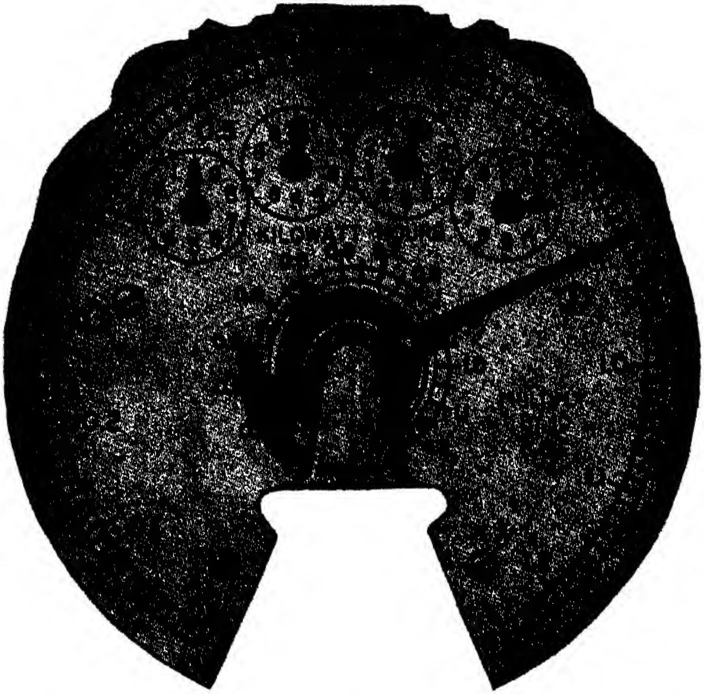


FIG. 4,518.—Sangamo maximum demand register. The red hand on the inner scale shows the kilowatt rate. The long hand on the outer scale shows the highest demand since the last reading. *In operation* the register works on the Merz principle in which the pointer is advanced over the demand scale at a speed proportional to the rate of energy consumption. The actuating mechanism is returned to its starting position at the end of a predetermined time interval, leaving the pointer at the highest position to which it has been carried in any one or more equal time intervals. The pusher arm is returned to zero by means of a cantilever resetting spring operated by a simple arrangement, consisting of two cams revolving at different speeds and having segments cut out to allow a pin to drop when the openings in the cams register at the end of each time interval. The operation of the register is described in detail in fig. 4,519. A manual reset with usual arrangement for sealing, is mounted on the glass meter cover, by which the indicating pointer may be returned to its zero position at reading intervals. A synchronous motor is used as a timing element.

Thus, the electrical element of certain demand meters is similar to an ordinary ammeter or watt meter of the deflection type, and in others it is a watt hour meter or other integrating meter, and in still others it is a resistance coil which introduces a heating effect which is interpreted in terms of amperes or watts.

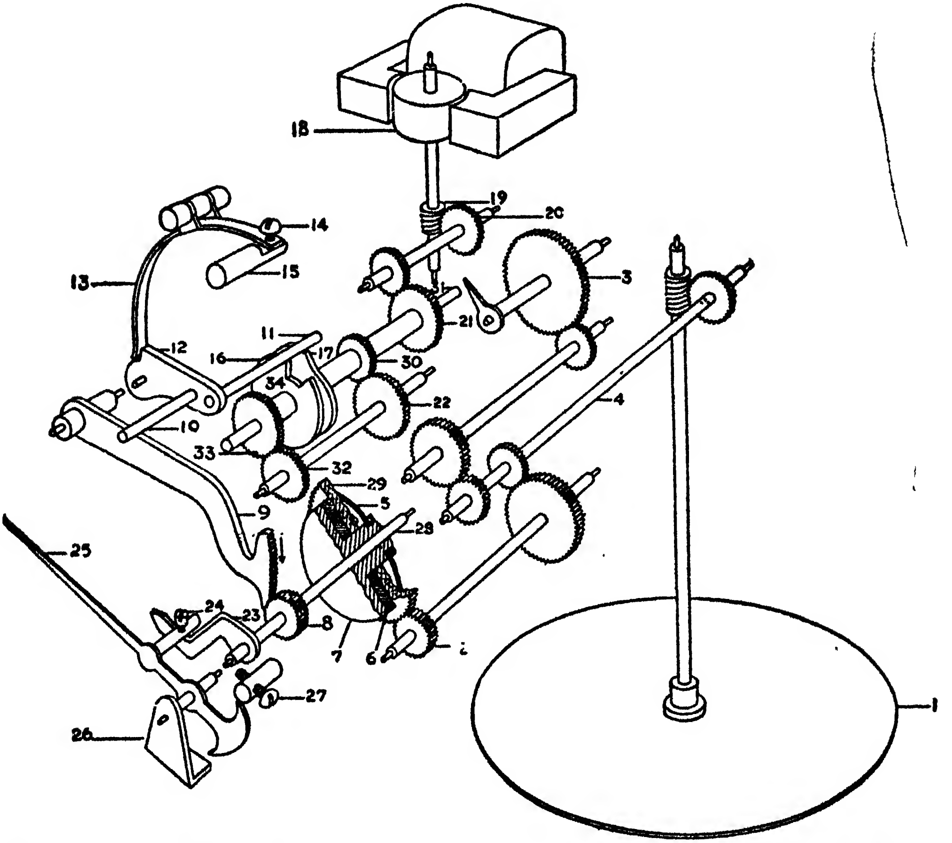


FIG. 4,519.—Diagram of Sangamo maximum demand register. *In operation,* register 3, is driven through the usual train of gearing from the watt hour meter disc 1. Shaft 4, through gears, also drives shaft 28, which carries the pusher arm 23. This pusher arm rotates at a speed proportional to the rate of energy consumption, and, as it travels across the scale, it pushes the indicating sweep hand 25. The power from the watt hour meter is transmitted through a friction clutch that couples gear 6, to shaft 28. The reseting mechanism, which converts this indicator into a maximum demand indicator, is operated by the synchronous motor 18, which through worm reduction and gears, operates two cams 16 and 17. Cam 16, through double reduction 30 and 22, 32 and 33, operates at one speed, while cam 17, operates sixteen times faster on intervals greater than five minutes, while on five minute intervals, 50 or 60 cycles and all 25 cycle fifteen minute intervals or less, the ratio is 4 to 1. On the face of cam 16, rides a pin 11, which is carried on an arm 12, and held in positive contact by a cantilever spring 13. When cam 16, is in such position that the notch 34, is below the pin, then the pin 11, rides on cam 17, and when the low side of cam 17, comes under the pin, it drops into the notch. Then through pin 10, arm 9, which carries a toothed sector, it is pushed down, and through pinion 8, rotates the pusher arm 23, back to zero. The power from the cantilever spring 13, pushing through pin 10, or arm 9, is sufficient to overcome the friction clutch and return the pusher arm to zero, the zero point being determined by the adjustment screw 27, which acts as a stop. This operation is performed quickly

The timing element of a demand meter is *the mechanism or that feature of the device through which the demand interval is introduced into the result.*

While the principal function of the timing element of a demand meter is to fix the demand interval, its subsidiary function in the case of certain types of demand meters is to provide a record of the time of day at which any demand has occurred.

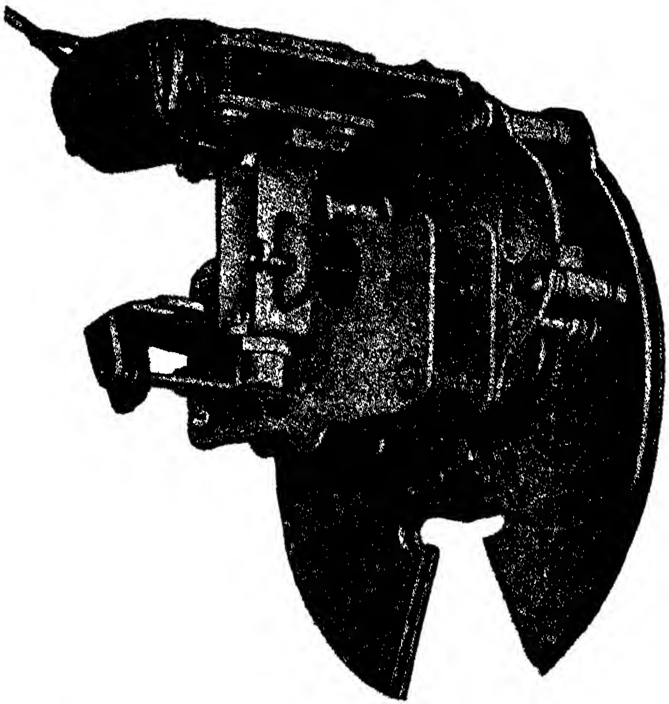


Fig. 4,520.—Sangamo maximum demand register; rear view.

Fig. 4519.—*Text Continued.*

and cam 17, then raises pin 11, which by that time, is picked up by cam 16, and carried until the next interval occurs. The normal rotation of shaft 28, by the watt hour meter disc, returns the arm 9, to position ready for the next resetting. The indicating hand 25, due to friction in the spring bearing 26, remains in whatever position the pusher arm leaves it. The co-ordination between pusher arm 23, and indicating pointer 25, is attained by means of adjustment screw 24. The tension of the cantilever spring 13, is adjusted by means of screw 14.

The timing element consists either of a clock or its equivalent (for example an electric motor) or of a lagging device which delays the indications of the electrical element.

In order that the measurement of electrical quantity as made by the electrical element may be combined with the measurement of time as made by the timing element, a further element, the recording element, is required.

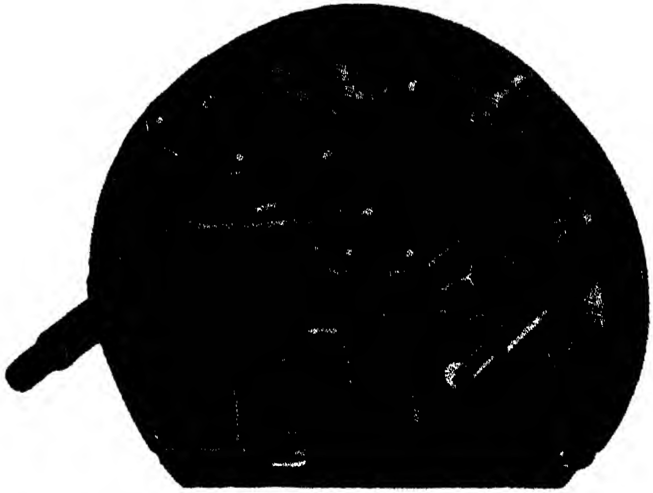


FIG. 4,521.—Duncan *a.c.* demand watt hour meter register, rear view showing motor.

In many important classes of demand meters, this is separate from the electrical and timing elements, but in other classes the electrical, timing and recording elements are inter-constructed.

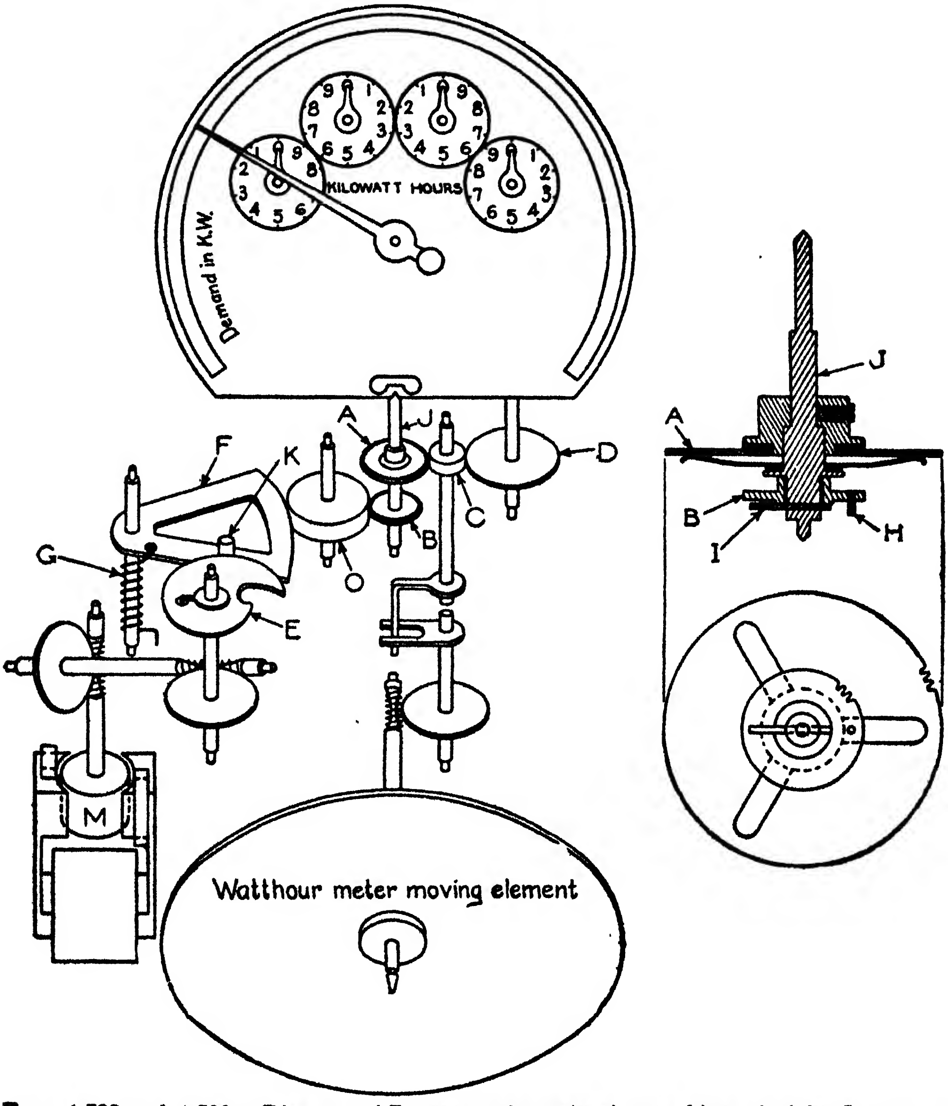
Classification of Demand Meters.—There are several types of demand meters to meet the varied requirements of service, and they may be classified as:

1. Integrating; 2. Lagged;
3. Recording.

Briefly:

An integrating demand meter is *one which indicates or records the maximum demand obtained through integration.*

NOTE.—The word *integrate* means *to give the sum total of.*



Figs. 4,522 and 4,523.—Diagram of Duncan register showing working principle. *In operation,* the watt meter moving element drives the watt hour dials through the gears C and D, direct and the demand pointer through the clutch gear A, which is shown in detail in fig. 4,523. The demand pointer is reset to zero at the end of each demand interval through the agency of a synchronous timing motor shown at M. The timing motor runs continuously at synchronous speed and through a proper gear reduction drives the cam E, so that it makes one complete revolution each demand interval. This cam moves a gear sector F, against a spring G. The gear sector F, is continuously in mesh with B, the other gear wheel

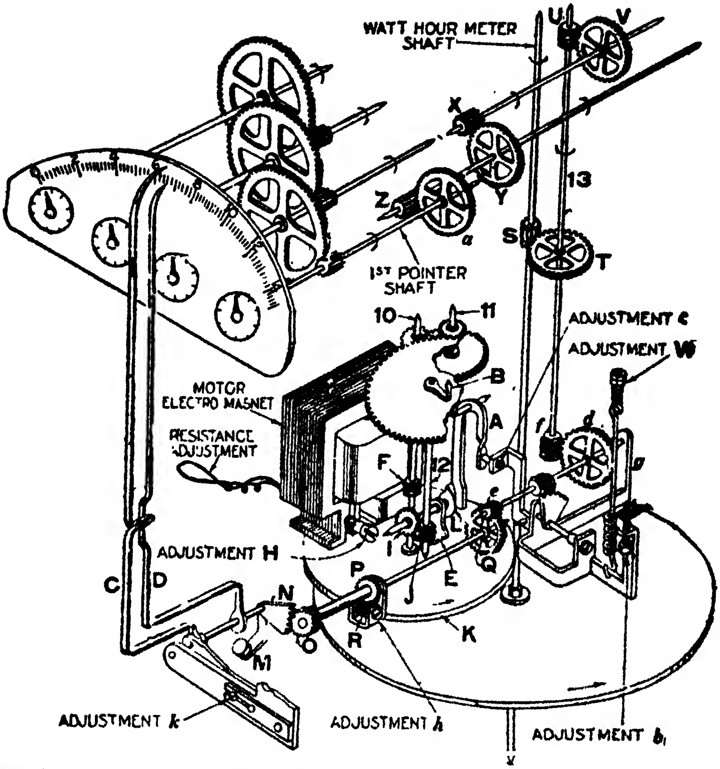


Fig. 4,524.—Diagram of Westinghouse type OA, single phase demand meter. ***Adjustments:*** 1, *Time adjustment*. The motor speed should be 200 *r.p.m.* for all intervals. As it is impossible to check this speed directly, a small white pointer is provided on the No. 12 shaft. This shaft makes four revolutions per minute (except for 60 minutes, which has a speed of 2.4 *r.p.m.*) when the motor disc is revolving at proper speed of 200 *r.p.m.* A small black spot which may be used for timing is placed on one spoke of the gear wheel on No. 12 shaft, as many prefer this method of timing. The motor speed is adjusted by the motor adjustment screw H. Turning the screw *in* increases the motor speed. This adjustment gives a range of approximately 15 per cent change in the motor speed. If sufficient adjustment cannot be obtained with this adjustment, further adjustment is obtained by adjusting the resistance in the secondary of the motor circuit, very similar to the manner in which

Figs. 4,522 and 4,523.—*Text Continued.*

of the friction clutch, through suitable gearing such as O. The pin H, is fixed in gear B, while the pin I, is fixed in the shaft J, carrying the demand driving pointer. Gear B, is free to move on shaft J, until the pins come into action. As the watt hour meter advances the demand pointer through gears C and A, A drives the shaft J, through a friction clutch as shown. At the end of the demand interval the roller K, drops off the tip of the cam E, and the spring G, forces the sector gear F, back. This in turn reverses the motion of the gear B. When B, is reversed the pin H, picks up the pin I, in the shaft J, and slips J, through the friction clutch returning the demand driving pointer to its zero position.

An integrating demand meter consists of a device in combination with an integrating meter whereby the energy consumption as measured by the meter is registered from time to time in such a way that the maximum demand may be determined from the record.

There are two types:

FIG. 4,525.—Duncan maximum demand watt hour meter register dial; front view.

FIG. 4,524—*Text Continued.*

the power factor adjustment is made on the polyphase type OA watt hour meter. Increasing the resistance of the motor secondary circuit decreases the motor speed and decreasing the secondary resistance of the motor circuit increases the motor speed; 2, *Zero adjustment.* Turning worm R (adjustment *h*,) in clockwise direction moves the white pointer up scale; 3, *Adjustment b* determines the depth of mesh of the worm wheel *d*, with the worm *f*. This should be adjusted so that the teeth on the worm wheel do not mesh the full depth of the thread on the worm and cause an excessive friction load on the No. 13, shaft; 4, *Adjustment c*, is provided to insure proper connection between the link A, and the lever *g*. This adjustment should be made so that the worm wheel *d*, will be moved out of mesh with the worm *f*, a distance of approximately 1/32 in. during the demeshing operation; 5, *Adjustment k*, is provided on the front of the register near the bearings of the pointers for adjusting the spring tension, and hence the friction holding the maximum demand pointer. Moving the small screw *in* increases the friction holding the black pointer in position of maximum demand.

NOTE.—No one except an experienced demand meter expert should attempt either adjustments or repairs. If convinced a demand register be not working properly, the best thing to do is to return it to the factory for attention.

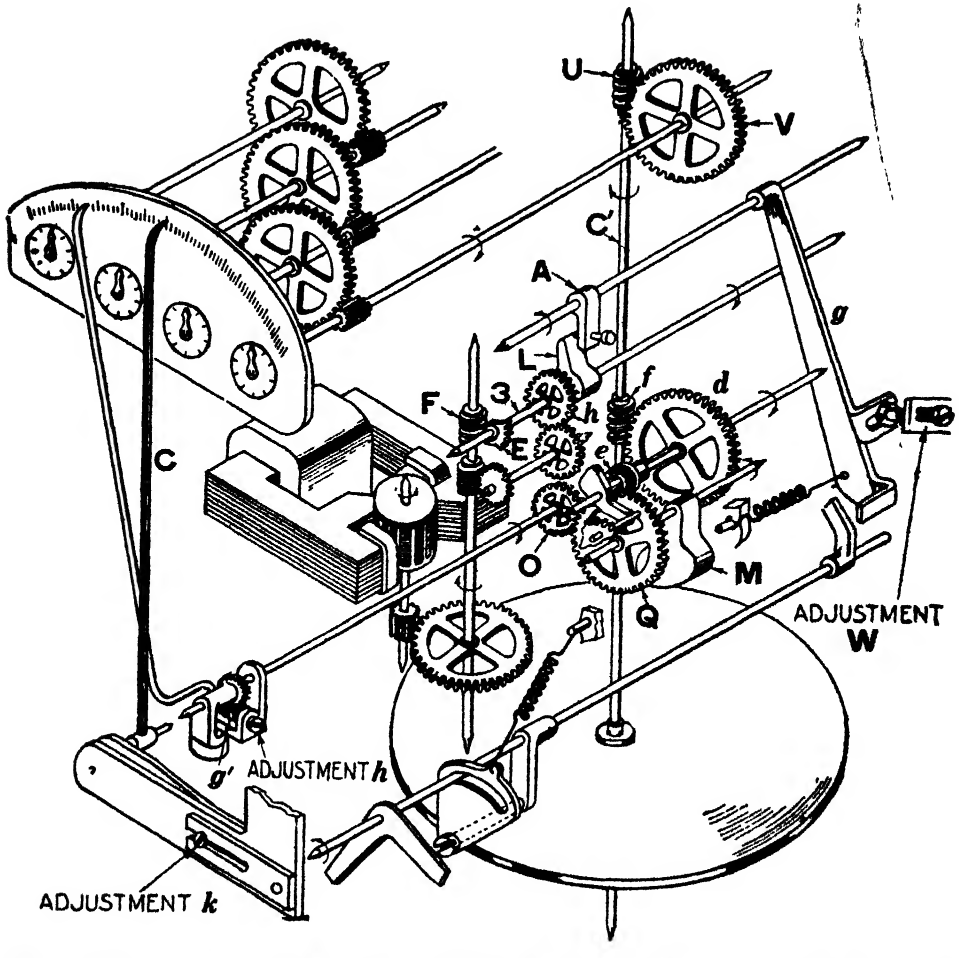


FIG. 4,526.—Diagram of Westinghouse type OB, demand register. *In construction,* the gearing of the register consists essentially of three sets: the watt hour pointer gearing, the demand pointer gearing and the motor gearing. As shown, there are two worms on the upper disc shaft. This is to simplify the diagram. Actually, these worms are mounted on the second shaft of the register. The moving element is connected to the register by means of a pinion and gear. *In operation,* the upper worm U, drives the worm wheel V, and thus rotates the first pointer shaft of the watt hour dial. The lower worm *f*, advances the demand pointer by driving the worm wheel *d*, and gears and pinions E, Q, O. As in the OA meter the worm wheel *d*, shaft of this set of gearing has one bearing in a lever *g*, which permits the worm wheel *d*, to be demeshed from the worm *f*, thus allowing the white pointer to be returned to zero by gravity weight M. The maximum demand (black) pointer C, is advanced by the (white) pointer D, and held by friction in the position of maximum deflection of the white pointer. The third or motor set of gearing, determines the length of the time interval. The synchronous motor runs at 600 *r.p.m.* on all 60 cycle meters. This

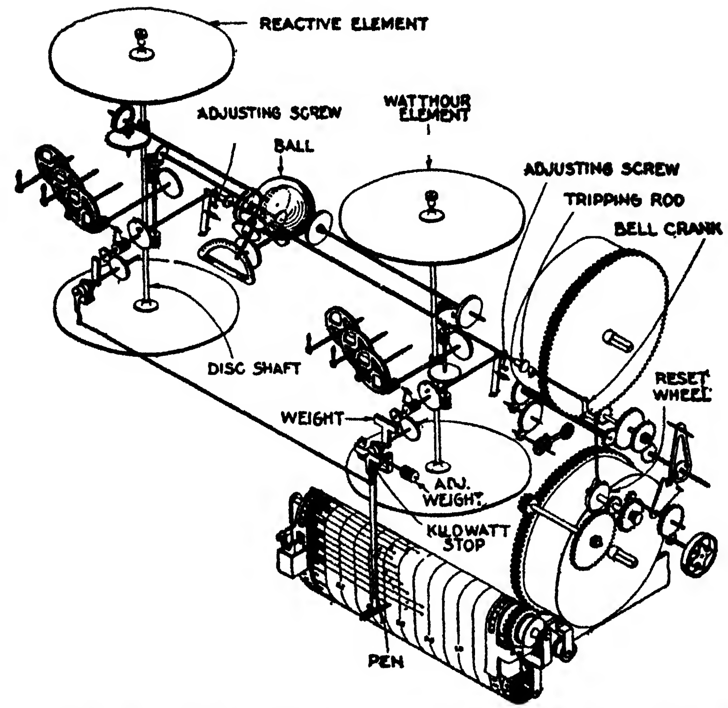


FIG. 4,527.—Elementary diagram of Westinghouse type R1 *kva* recording watt hour demand meter. The meter gives direct reading of power factor, total *kw* hours, total *kva* hours, *kw* demand and *kva* demand for any interval. The power factor and reactive *kva* hours for any time interval, such as at the time of maximum demand, may be calculated from the chart. The *kva* demand record is made graphically upon a moving paper chart by a pen that is driven from the ball so that its rate of movement across the paper is proportional to the total *kva* in the metered circuit. The *kw* demand is obtained by means *of a stop* driven by the *kw* gear train. At the end of the time interval the pen is disengaged from the *kva* gears and falls back until arrested by this *stop*, it pauses here momentarily and then is reset to zero. As the paper chart is moving during this *resetting period* distinct vertical marks are made on the paper at both the *kva* and the *kw* demand points.

FIG. 4,526.—*Text continued.*

speed is reduced by suitable gearing to give one revolution of the shaft 3, in the time interval of the register, 15 minutes or 30 minutes, etc. On the same shaft 3, but free to rotate about the shaft, is the worm wheel sector E, and the cam L, which are rigidly mounted on the same hub. A pin on the gear *h*, slowly rotates the worm wheel sector E, until it reaches the worm F, on the high speed motor shaft. Since this shaft makes 100 *r.p.m.* the worm wheel sector E, is quickly passed through the worm F. As the worm wheel sector E, passes through the worm F, the cam L, strikes the lever A, which transmits the motion of the cam to lever *g*, thus demeshing the worm wheel *d*, from the worm *f*, and allowing the white pointer to return to zero. The period for the worm wheel sector E, to pass through the worm *f*, is selected to allow ample time for the white pointer D, to return to zero. The time of the demeshing operation is approximately three seconds, which is a negligible quantity when compared to the time interval of the register.

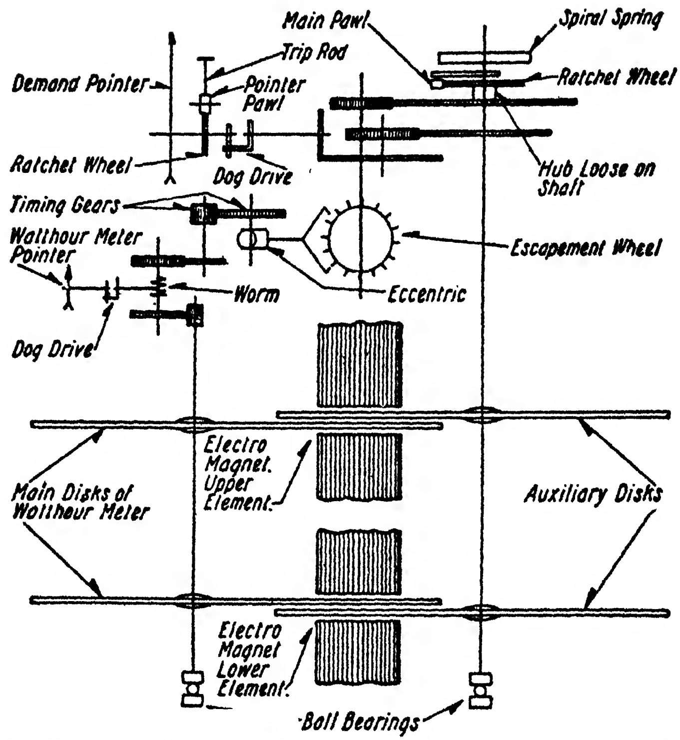


FIG. 4,528.—Diagram of Westinghouse type RO polyphase watt hour demand meter. ***Designed to meet*** the requirements of central station meter service. It is a single instrument that records both the kilowatt hours consumed and the maximum demand in kilowatts. It is installed as an ordinary watt hour meter and requires no additional apparatus or wiring. The maximum demand is indicated directly by a pointer sweeping over a four inch dial, the integrated load being registered on the usual four dial counter. The demand pointer is reset manually by pressing a button at the top of the meter cover. The meter has a definite time constant, yet requires no clock or contacts. The watt hour meter element is provided with micrometer light load and full load adjustments. The demand meter element is provided with a micrometer zero adjustment and a spring clamp for making changes in length of spring. These adjustments are accessible at the top of the instrument. ***In operation,*** when power flows through the instrument the main discs begin to rotate at a speed proportional to the load, driving the watt hour gear train and oscillating the escapement claw. The auxiliary discs tend to deflect the pointer instantly to indicate the load, but is prevented by the escapement claw engaging its wheel. As the claw oscillates, the teeth of the escapement wheel are allowed to pass, one by one, until the tension on the spiral spring balances the torque developed in the auxiliary discs. The system is then in equilibrium, the demand pointer indicating the load, and although the main discs continue to rotate so long as the load is maintained, no further deflection takes place, since *the escapement claw oscillates freely between the teeth of the escapement wheel.*

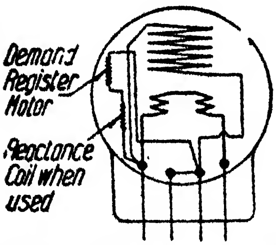
NOTE.—***The mechanism*** of the Westinghouse type RO polyphase watt hour demand meter is very similar to the ordinary clock; the auxiliary discs furnishing the power for driving

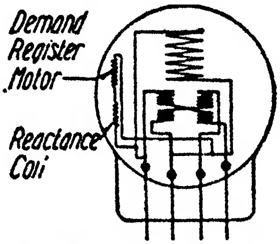
1. Those showing the energy consumption in definite and consecutive demand intervals occurring at arbitrarily chosen times such as 2:30 to 3:00 to 3:30, etc.

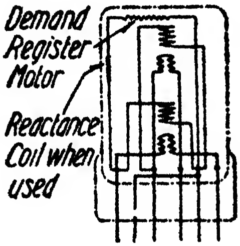
The maximum demand corresponds to the greatest energy consumption in an interval.

If recording on a tape or chart, the demand for any interval can be ascertained and also the time of day at which it occurred.

If indicating by means of a hand and dial, only the maximum demand is obtainable at any subsequent time.







FIGS. 4,529 to 4,531.—Connection diagrams for Westinghouse type OB demand register. Fig. 4,529, single phase 2 wire; fig. 4,530, single phase 3 wire; fig. 4,531, two element, three phase 3 wire self contained.

2. Those recording on a tape or chart the number of equal and relatively small amounts or blocks of energy with respect to a separate and continuous record of time.

The maximum demand is obtained by counting the number of such recorded points occurring within the demand interval, the time of the beginning of the interval being so chosen that the interval will include the maximum number of points. From the record, the demand for any

NOTE.—*Continued.*

the escapement like a main spring, while the rate of the movement is controlled by the motion of the main discs, which perform the function of a balance wheel. The escapement wheel and claw have radial teeth to prevent an interchange of energy between the main and auxiliary discs. It is to be observed that the function of the main discs are simply to regulate the rate of deflection of the auxiliary discs. They supply no power whatever except the negligible amount required to oscillate the escapement claw.

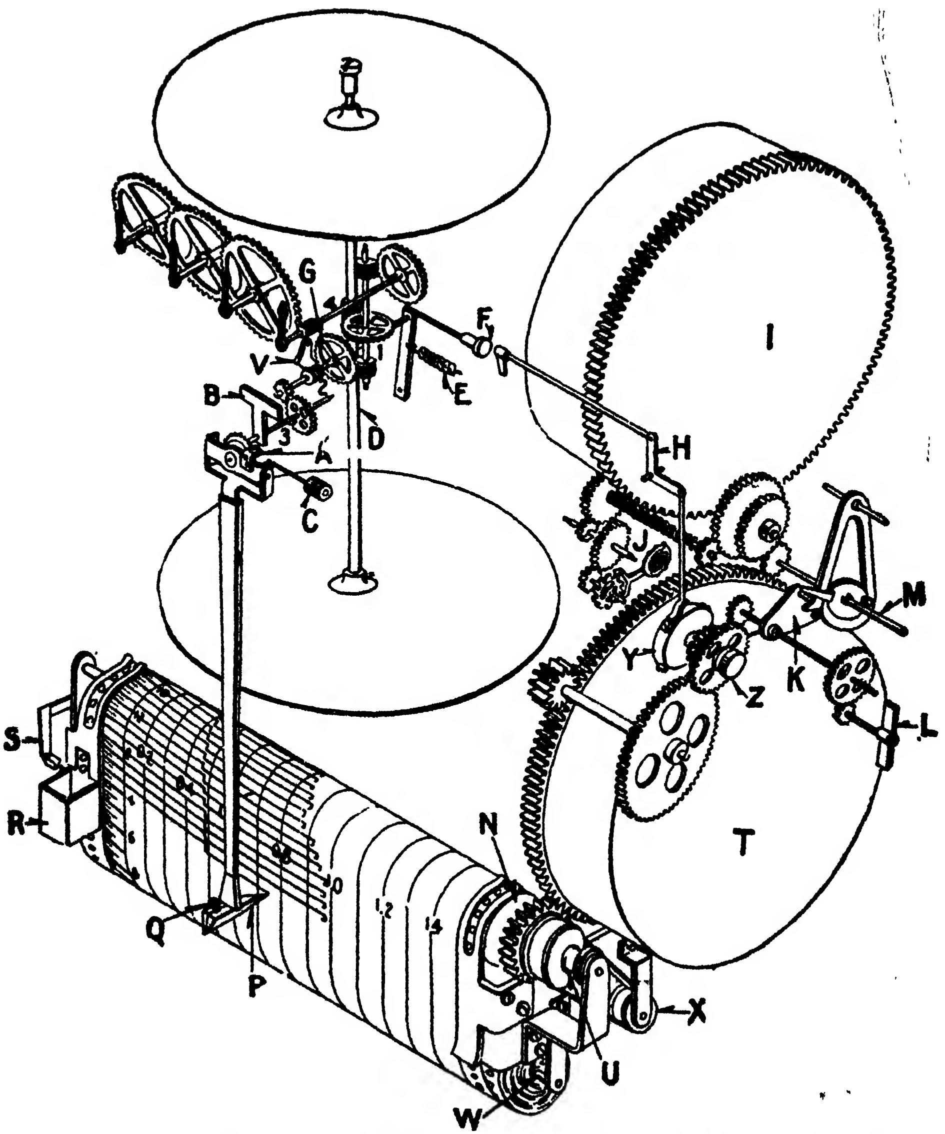


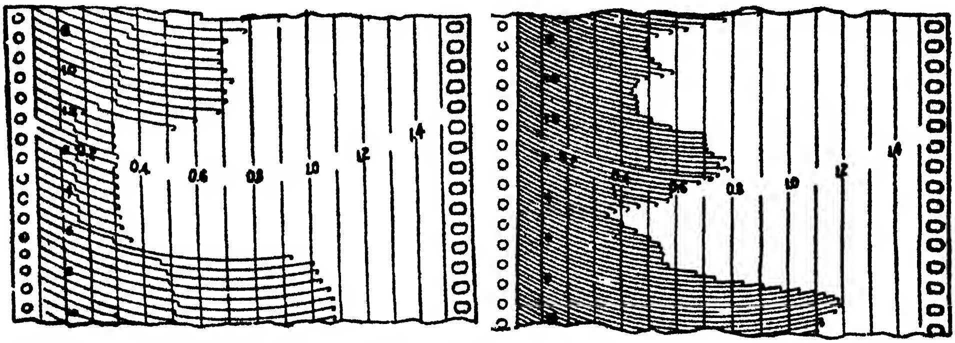
FIG. 4,532.—Westinghouse type RA recording watt hour demand meter. *In operation,* under load the disc shaft D, registers watt hours on the counter through the gearing of the shaft assemblies 1 and 4. At the same time, the ink carrying pen P, is positively advanced through shaft assemblies 1, 2, and 3 At the end of the time interval the tripping rod,

interval can be obtained and the time of day at which it occurred. These instruments differ from those of Class 1, in that the time of the beginning of the interval is not arbitrarily fixed.

A lagged demand meter is one in which the indication of the maximum demand is subject to a characteristic time lag.

Lagged demand meters are so constructed as to require a certain time interval for the indication to reach the point corresponding to the value of the load.

There are two types.



FIGS. 4,533 and 4,534.—Chart samples for Westinghouse type RA recording watt hour demand meter. Fig. 4,533, 30 minute interval; fig. 4,534, 15 minute interval.

FIG. 4,532.—*Text Continued.*

pushing against the rod F, moves the small pivoted frame work which carries one of the bearings of shaft 2, and disengages the worm wheel of shaft 2, from the worm of shaft 1. The weight of the pen and pen arm is counter-balanced by weight B, and the adjustable weights C, are so placed as to cause the pen to immediately swing to the zero position when its driving gears are disengaged. When falling to the zero position, the rotation of the worm on shaft 2, moves the swinging sector V, against which the pin G, of the gear wheel eventually strikes and thus limits the backward movement of the pen. When pressure on rod F, is relieved, the spring E, returns the pen mechanism into mesh. The upper clock spring I, actuates the timing device. The speed of the clock is controlled in the usual manner through the escapement mechanism on which the torque is held constant by a differential spring governor. At the proper time interval, the trip on shaft M, allows the shaft K, to rotate with a speed of rotation that is limited by the governor. Simultaneously, the reset wheel Y, is given a quarter turn, causing a movement of the bell crank H, and a consequent tripping of the pen. Just before the pen begins to fall back, however, the large gear on the spring drum rotates a fraction of a turn and advances the paper roll. The paper chart unrolls from spindle W, passes upward over the face of roll N, and rerolls on the belt driven spool X.

1. Those in which the speed of the indicator in moving up its scale under constant load, is constant, or at any load, is proportional to the load.

2. Those in which the speed diminishes with the time of the deflection. The demand interval for meters of this class is ordinarily considered to be the time required for the instruments to indicate 90 per cent of the full value of a steady load which is thrown suddenly on it.

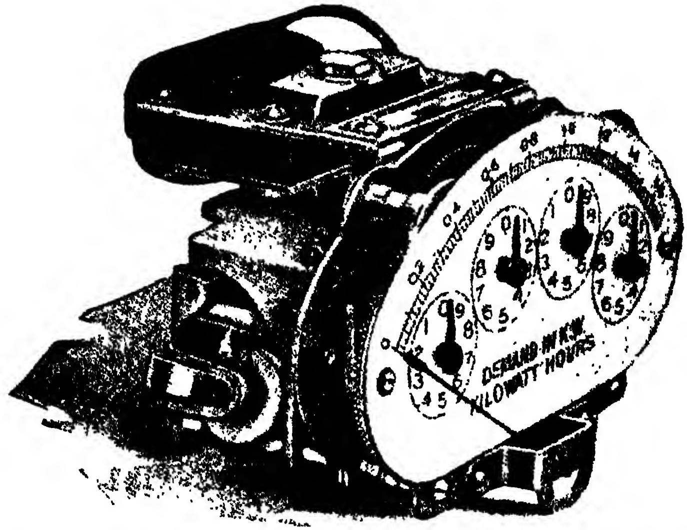
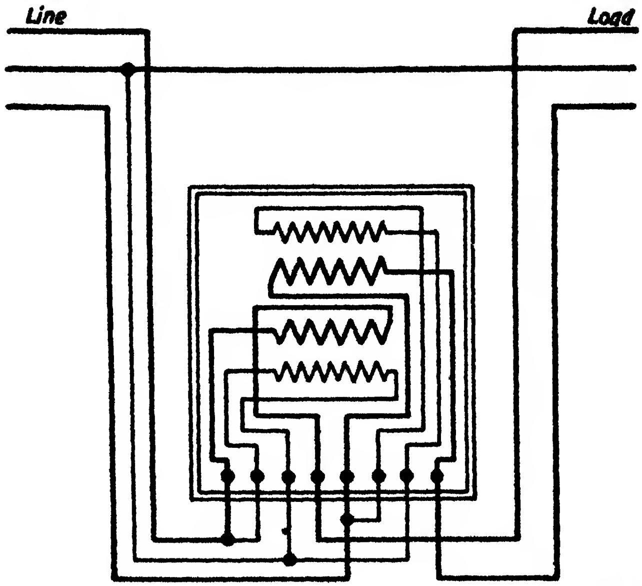


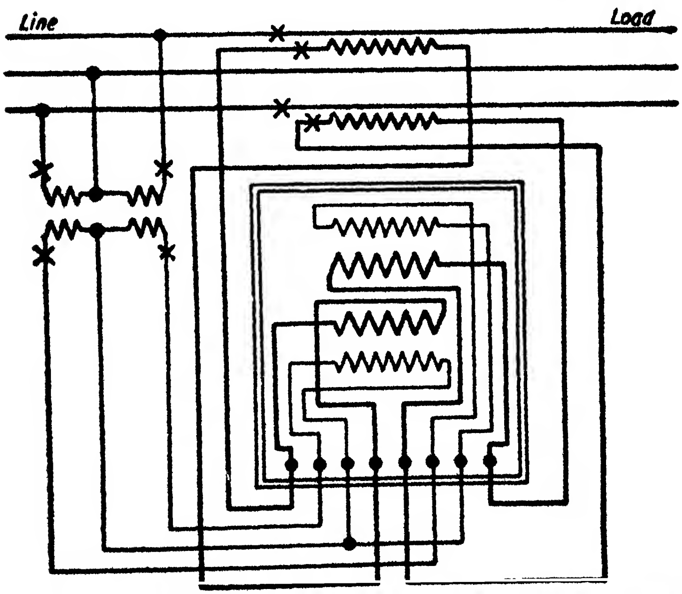
FIG. 4,535.—Front view of Sangamo maximum demand register, showing *kw*. demand scale and *kw*. hour dials for a 10 ampere, 110 volt, single phase meter.

A recording or curve drawing demand meter is *one which gives the load time curve of an installation or system.*

The demand interval may be of any specified length, and the demand periods may be taken as beginning at specified times of the day or may be timed so as to include the maximum average load occurring in any period of the chosen duration. Curve drawing or graphic recording instruments are obtainable in many varieties and makes.

The various types of demand meters in general use are shown in the accompanying illustrations.





FIGS. 4,536.—Westinghouse recording demand watt hour meter diagram of connections for 2 or 3 phase, 3 wire, without transformers.
FIGS. 4,537.—Westinghouse recording demand watt hour meter diagram of connections for 2 or 3 phase, 3 wire with current and voltage transformers.

TEST QUESTIONS

1. *What is a demand meter?*
2. *Define the term "demand meter."*
3. *What is understood by the term "stand by service"?*
4. *What kind of a quantity is measured by demand meters?*
5. *What is the electrical element of a demand meter?*
6. *Describe the construction and operation of the Sangamo maximum register.*
7. *What is the time element of a demand meter?*
8. *Give classifications of demand meters.*
9. *What is an integrating demand meter?*
10. *Name two types of integrating meter?*
11. *Describe a lagged demand meter.*
12. *Name two types of lagged demand meters.*
13. *What kind of a record is made by a recording or curve drawing demand meter?*
14. *Describe the construction and operation of a curve drawing demand meter.*

CHAPTER 86

Miscellaneous Meters

In addition to the meters already described in the preceding chapters, there are a few instruments which should be here considered; such as

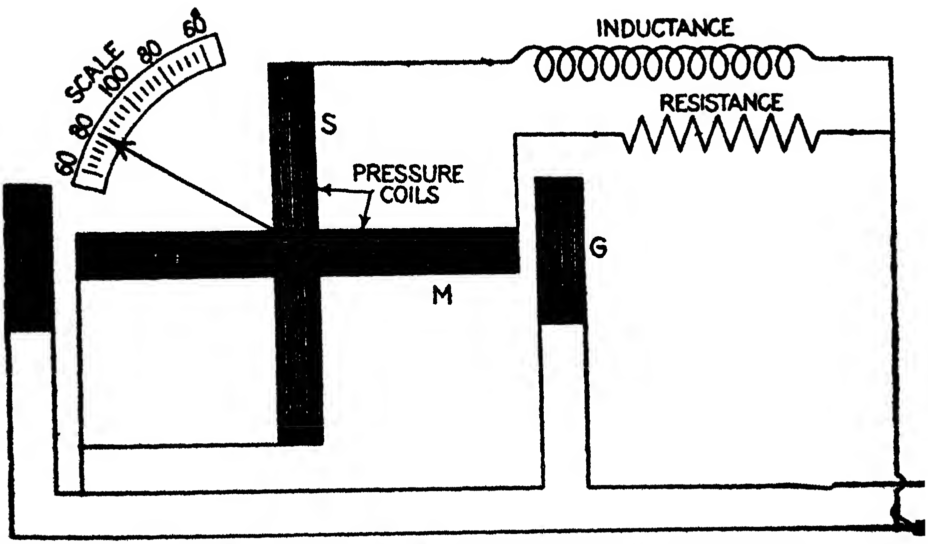


FIG. 4,538.—Single phase power factor meter of the rotating field or disc type.

1. Power factor meters;
2. Phase indicators;
3. Synchronism indicators:

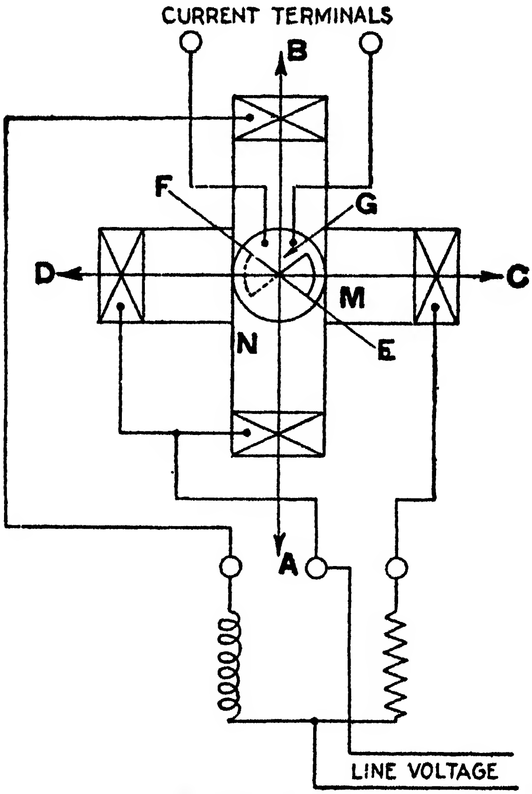


FIG. 4,539.—***Elements of rotating field type power factor meter*** illustrating principle of operation. ***In construction,*** N and M, are two coils fixed at right angles to each other with their axes in the same plane. The coils are wound with a large number of turns of fine wire and are connected in a split phase arrangement, one coil being connected in series with an inductive resistor and the other in series with a non-inductive resistor. The two sets are then connected in parallel across the line of the circuit to be measured. The currents in these two coils are almost in quadrature so, when the coil M, is active in producing a field in the direction AB, the current in coil N, is zero. One quarter cycle later, the current in coil M, becomes zero and the current in coil N, is producing a field in direction DC. This is not a sudden jump, but a gradual decrease of current in M, and a gradual increase of current in N, thereby producing a steadily progressing shifting of the resultant magnetic axis from AB, to CD. In another quarter cycle, the current in N, is zero, but the current has built up in coil M, in the opposite direction, changing the axis of the field to direction BA. In another quarter cycle, the coil M, is again zero, but the current has reversed to maximum in coil N, producing a field in direction DC. Therefore, in every cycle, the axis of the magnetic field has made one gradually changing sweep completely around the whole circle, producing the so-called "rotating field." Inside of the two coils N and M, is placed an iron vane or armature, magnetized by a coil G, and pivoted so that it can rotate with its axis in the plane of the axes of the coils M and N. Through this coil passes a current in phase with the current of the circuit to be measured. As the iron vane will be attracted or repelled by the fields of the coils N and M, it takes up a position so that when the current

4. Frequency meters;
5. Surge indicator, or klydonograph.

Power Factor Meters.—Meters of this class indicate the phase relationship between pressure and current, and are

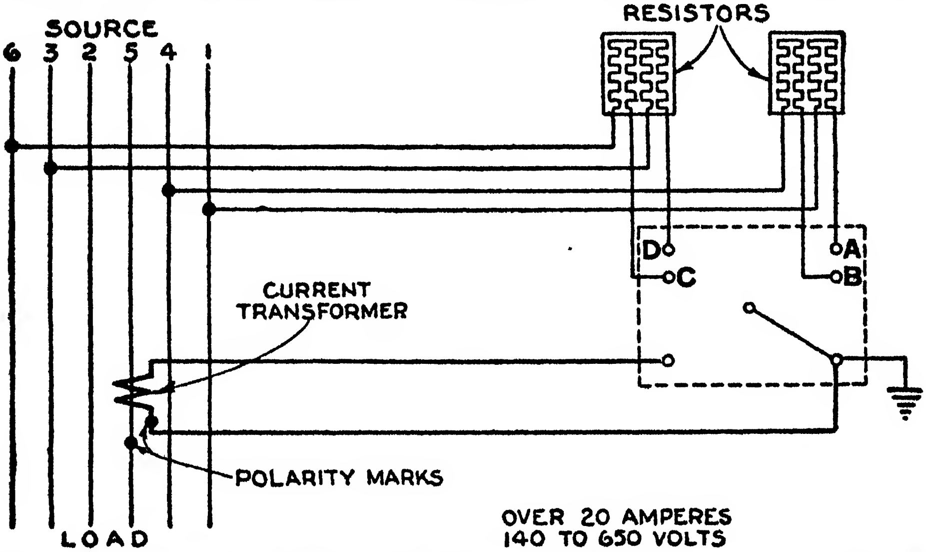


FIG. 4,540.—Connection diagram for General Electric power factor meter; 6 wire, 4 phase circuits.

FIG. 4,539—*Text continued.*
wave reaches its maximum, the axis of the iron vane will coincide with the axis of the rotating field at that particular instant. Thus, if the current reach a maximum when the rotating field has reached the position AB (when the current in coil N, is in phase with the current in coil M), the vane will assume a position AB. Should the current lag, however, and not reach a maximum until the field has rotated to position EF, then the vane would assume the position EF, and, by suitably graduating the scale, will read directly the cosine or sine of the angle between AB and EF.

NOTE.—In fig. 4,539, should the current lag 90°, the rotating field would have advanced to CD, before the current reached its maximum and the vane would assume position CD. The vane will assume a definite position for any phase relation between current and voltage anywhere in the whole 360° of each cycle. From the foregoing it is readily seen that the deflection depends on the angle between current and voltage, but since each angle indication is marked with the cosine or the sine instead of the angle, the meters read directly in power factor and reactive factor. Because it is impossible to have the current lag exactly 90° in a split phase arrangement, the coils M, and N, are not exactly 90° apart. Thus if the coils were placed exactly 90° apart, the rotating field would shift slower from AB, to CD, than it did from CD, to BA, and produce a distorted scale. Therefore, the angle BOD, is made greater than the angle DOA, producing an evenly rotating field, and a scale with symmetrical quarters.

therefore sometimes called *phase indicators*. There are two types:

1. Watt meter type; 2. Disc, or rotating field type.

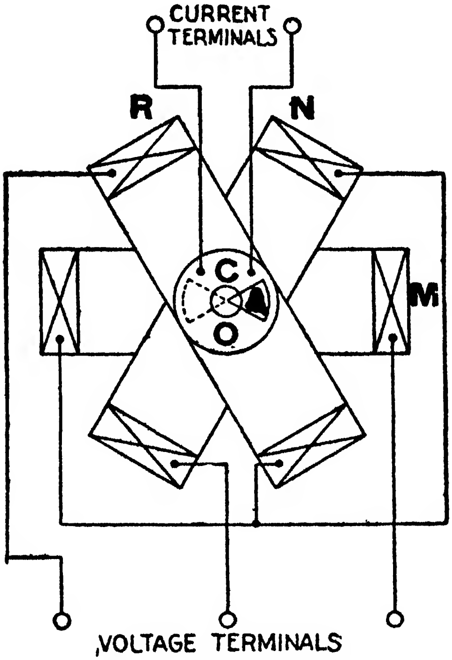


FIG. 4,541.—*Elements of three phase rotating field type power factor meter.* In the three phase instrument, the two voltage coils and the split phase resistor reactor, are replaced with 3 coils, wound with their axes, 120° apart, as here shown. By connecting in Y, and connecting to a three phase circuit, a uniformly rotating field is produced, giving the same characteristic scale marking as the single phase circuit wave produced. The only difference between the action of the single phase and the three phase instruments lies in the method of producing the rotating field.

Watt Meter Type.—

In this construction, the phase relation between the pressure and the current fluxes is such that on a non-inductive load the torque is zero.

For instance, in a dynamometer watt meter, the pressure circuit is made highly inductive and the instrument then indicates *volts*×*amperes*×*sin* ϕ instead of *volts*×*amperes*×*cos* ϕ, that is to say, it will indicate the wattless component of the power. A dynamometer of this type is sometimes called an idle current watt meter.

Disc or Rotating Field Type.—

A single phase power factor meter of the disc or rotating field type consists of two pressure coils, as shown in fig. 4,538, placed at right angles to each other, one being connected through a resistance, and the other through an inductance so as to "split" the phase and get the equivalent of a rotating magnetic field.

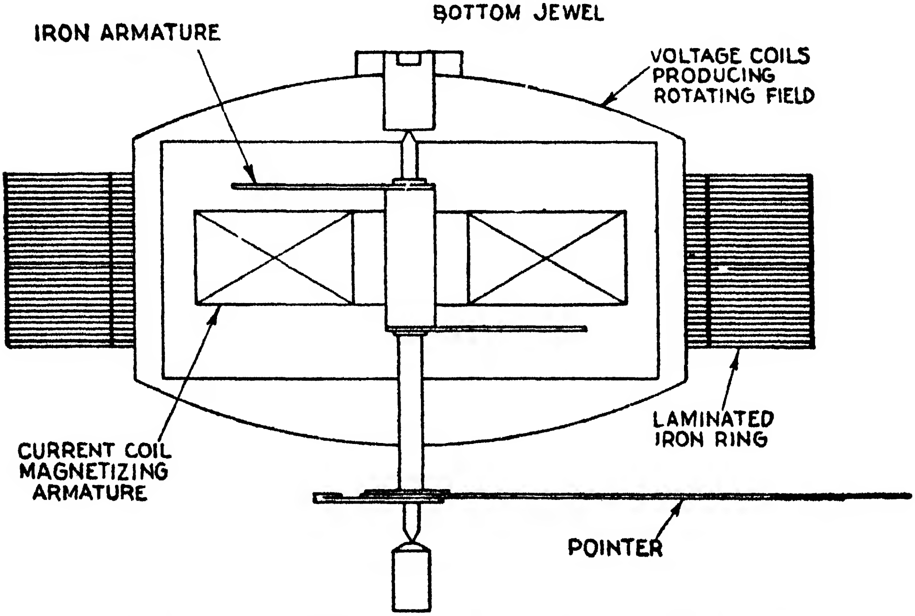


FIG. 4,542.—Sectional view of polyphase rotating field type power factor meter.

The coils are placed about a common axis, along which is pivoted an iron disc or vane. The magnetizing coils FG, are in series with the load. If the load be very inductive, the coil M, experiences very little torque and the system will set itself as shown in the figure. As the load becomes less inductive, the torque on S, decreases and on M, increases so that the system takes up a particular position for every angle of lag or lead.

Power factor meters are designed to show the power factors, lagging or leading, at which various lines are operating. These instruments are adapted for balanced systems only

In connecting, if it be found by trial that the needle swings to the wrong side of the scale with leading or lagging current, the potential leads to the line from the resistor should be interchanged at some point between the

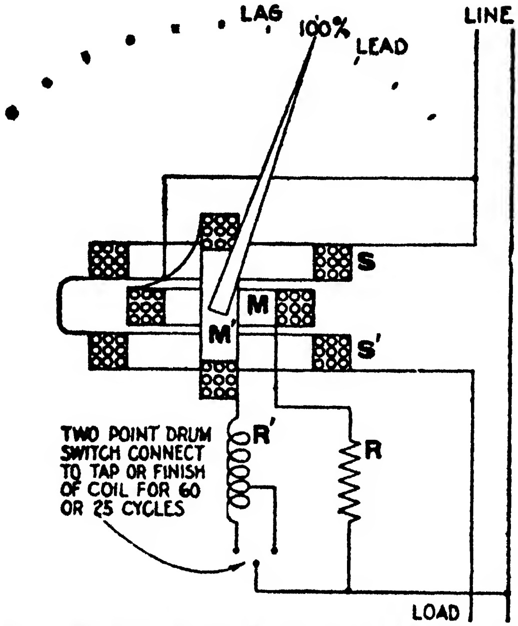


FIG. 4,543.—Diagram of single phase rotating field type power factor meter showing operation In this meter the spiral control spring is omitted, and electro-magnetic control provided. Two moving coils are used, rigidly fastened with their axes at right angles to each other. Coil M, is in series with a non-inductive resistor and the coil M′, is in series with an inductive reactor. Consequently, the current in M, is in phase with the voltage while the current in M′, lags almost 90° behind it. The stationary coils carry a current proportional to, and in phase with the current of the load being measured. At 100% power factor, the current in S S′, and M, are in phase; therefore, their axes tend to coincide. The current in M′, is almost 90° out of phase, consequently there is practically no reaction or attempt to align axes between M′ and S S′. However, should the current in S S′, lag 90° it would be in phase with the current in M′, and out of phase with the current in M. Then the coil M′, would have the greatest tendency to align its axis with that of S S′, and as the coil M, now has no such tendency, the result would be a movement of the pointer, attempting to bring about such alignment of axes. If the current should only lag 45°, then both coils would make equal efforts to align their axes with the axis of coils S S′, but since they cannot both attain their object, and since they are both rigidly connected, they take a resultant position which would be marked 70% power factor on the dial. For any degree of lag or lead of current, the two coils strike a resultant, depending on the phase angle between the main current in coils S S′, and the current in the coils M and M′. It will be seen that, since there is no control spring, and since the position assumed depends on the phase angle between the current and voltage (currents in M and M′) and not on their magnitude, the positions could be marked in degrees of phase difference. Instead of this, however, each position is marked with the cosine of the angle of phase difference and consequently reads directly in power factor. It may be said that the instrument responds to the angle, but indicates the cosine.

NOTE.—*In actual practice,* it is very rare to meet or measure power factors below 40%, so that the instrument is arranged to omit all power factors below 40% lag and below 60% lead thus making a symmetrical 90° scale containing all the practical working values met in actual service. The single phase instrument is slightly affected by large variations from the normal frequency.

resistor and the line, or between the resistor and the secondaries of the potential transformers, as conditions may require.

One method of checking the connections of a 3 wire, 3 phase power factor indicator in order to determine whether the current be leading or lagging the voltage of the circuit is to short circuit the current terminals of the power factor meters by means of a piece of wire. If the pointer move toward lag, then the connections are correct. This is true whether the instrument be indicating either a leading or a lagging power factor.

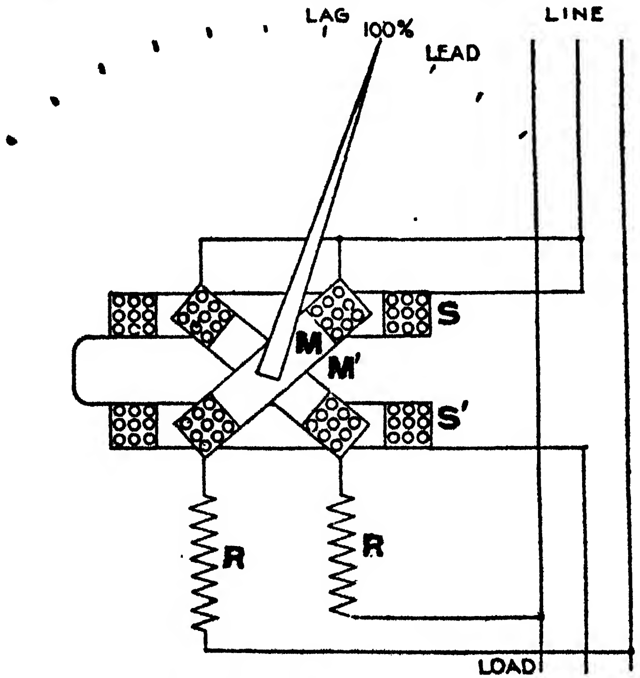


FIG. 4,544.—Diagram of three phase rotating field type power factor meter. The moving coils are connected in series with separate non-inductive resistors to two phases of a three phase circuit. The current is taken from the third phase. Consequently at 100% power factor, the current in one voltage coil leads the main current by 30° and in the other phase, it lags 30°. At 100% power factor, there is equal effort of coils to align their axes and the resultant position is that shown. Should the current now lead or lag, one or the other coil will have greater aligning effort, consequently changing the position of the moving element and assuming a definite position for each change of the phase angle or power factor. As in the single phase, the scale is marked in cosines, so that it reads the power factor direct. It covers a range of from 40% lag to 60% lead. As the 3 phase instruments contain no inductive circuits, they may be used on circuits of any frequency. Power factor meters attain their highest accuracy when the current is from 2 to 5 amperes and the voltage from 75 to 125 volts. The three phase instruments having only one current coil, do not record the average power factor of an unbalanced three phase circuit. They are designed for balanced circuits such as rotary converter or polyphase motor circuits.

Phase Indicators.—This type of instrument is intended for "phasing out" particularly in making relay connections or other connections where a current of a specific phase should be selected in regard to a particular voltage connection.

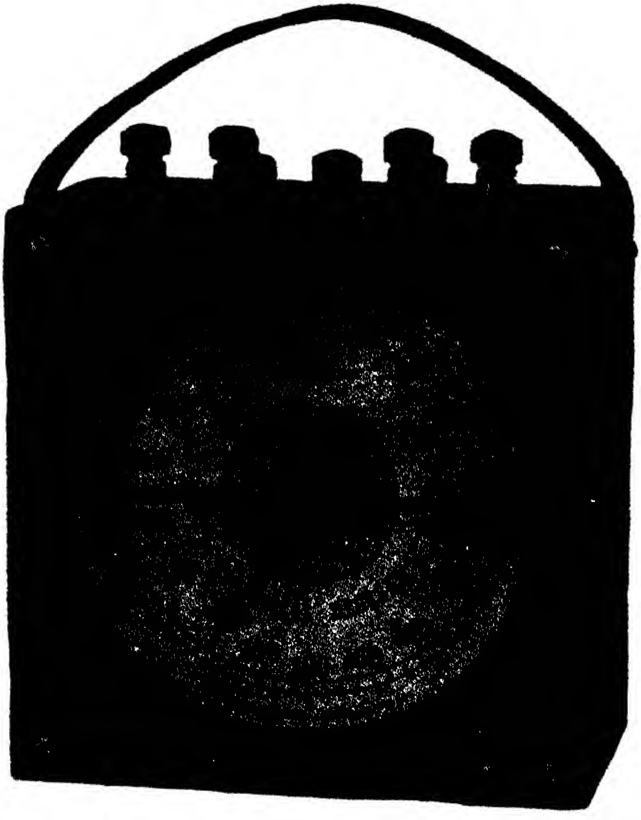


FIG. 4,545.—Westinghouse portable phase indicator.

The phase indicator makes it possible to determine exact phase relations and avoid incorrect connections which may cause costly failures of service.

In making any connection where a current of a particular phase should be selected in regard to a certain potential connection, the phase indicator is of value. The portable phase indicator, as shown in fig. 4,545, is a moving vane type instrument similar in operation and construction to a

power factor meter but having a uniform circular scale marked off in 360 electrical degrees.

It operates on the principle that a *suitably pivoted iron vane, when placed in a rotating field and magnetized by alternating currents, will assume a position depending on the phase difference between the current magnetizing the vane, and the voltage producing the rotating field.*

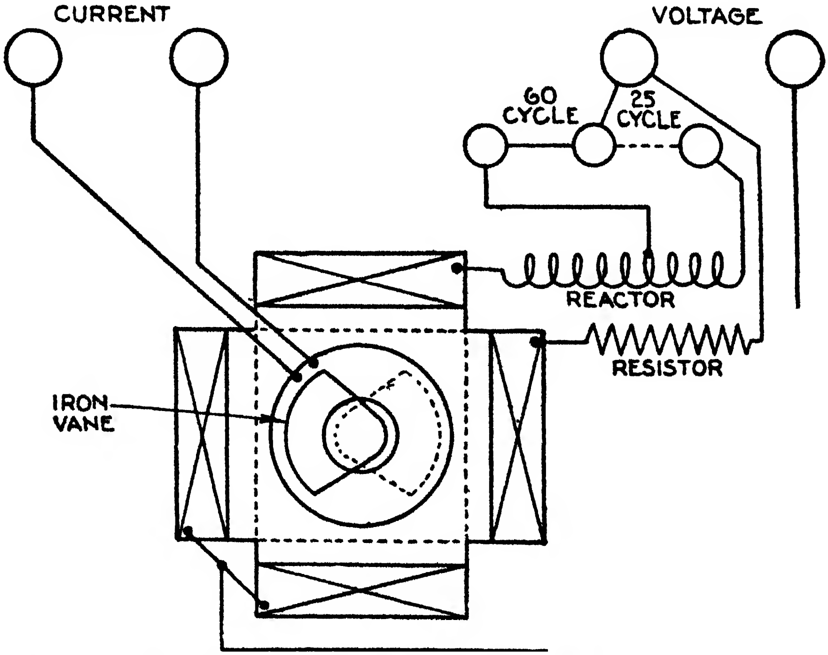


Fig. 4,546.—Diagram of Westinghouse portable phase indicator.

The rotating field is produced by a split phase winding connected to the voltage circuit. In this field is a movable iron vane magnetized by a stationary coil which is part of the current circuit. The iron vane, to which the pointer is attached, is acted upon by the rotating field, and the vane will take up a position so that when the current reaches its maximum, the axis of the iron vane will coincide with the axis of the rotating field at that particular instant.

The vane will assume a definite position for any phase relation between current and voltage. When used to determine the phase angle between

the current and voltage in, say, a power directional relay, the method is obvious and the results are easy to interpret.

The only difficulty likely to be encountered is when one of the vectors may be reversed 180°. In order to check this condition, it is well to examine the operation of the relay itself.

Synchronism Indicators.—These devices, sometimes called synchroscopes, or synchronizers *indicate the exact difference in*

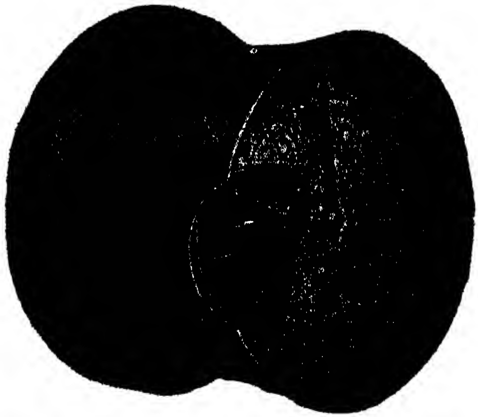
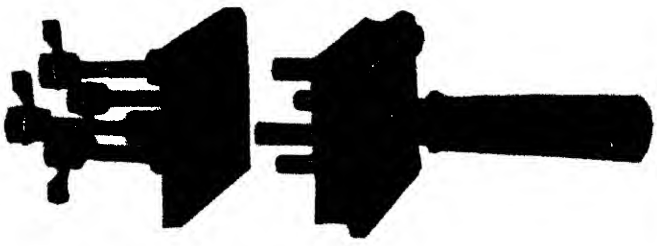


FIG. 4,547.—General Electric synchronism indicator showing relation between the motor and the pointer.



FIGS. 4,548 and 4,549.—Synchronizing receptacle and plug.

phase angle at every instant, and the difference in frequency, between an incoming machine and the system to which it is to be connected, so that the coupling switch can be closed at the proper instant.

There are several types of synchronizer, such as

1. Lamp or volt meter;
2. Resonance or vibrating reed;
3. Rotating field.

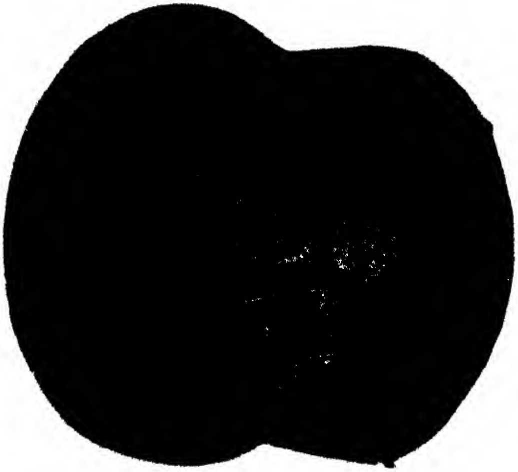


FIG. 4,550.—General Electric synchronism indicator with cover dial and pointer removed.

Lamp or Volt Meter Type.

The simplest arrangement consists of a lamp or preferably a volt meter connected across one pole of a two pole switch connecting the incoming machine to the busbars, the other pole of the switch being already closed.

If the machines be out of step, the lamps will fluctuate in brightness, or the volt meter pointer will oscillate, the pulsation becoming less and less as the incoming machine approaches synchronous speed. Synchronism is shown by the lamp remaining out, or the volt meter at zero.

Resonance or Vibrating Reed Type.—

This type operates on the same principle as the resonance type of frequency indicator, later described.

Rotating Field Type.—

The operation of the rotating field type depends on the production of a rotating field by the currents of the metered circuits in angularly placed coils, one for each phase in the case of a polyphase indicator. In this field is provided a movable iron vane or armature, magnetized by a stationary coil whose current is in phase with the voltage of one phase of the circuit.

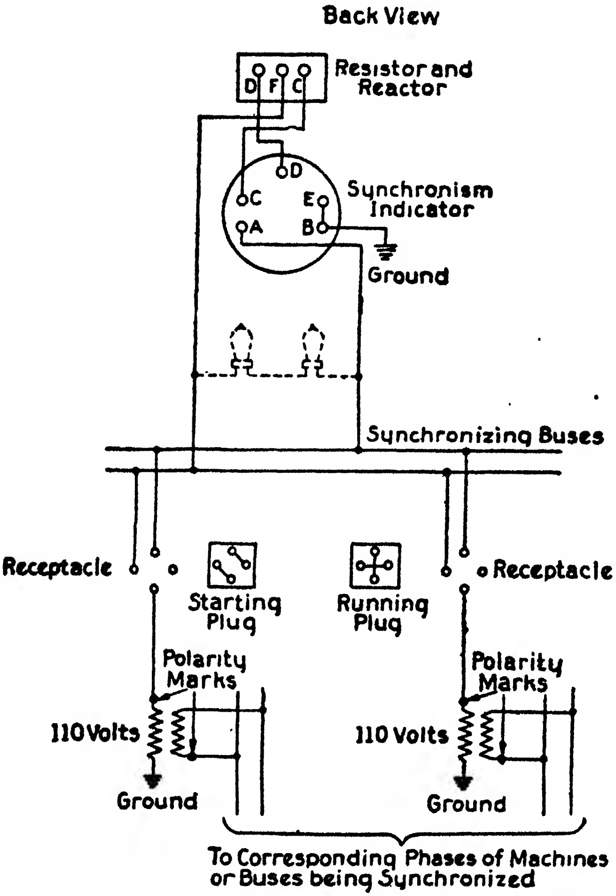


FIG. 4,551.—Connections of General Electric synchronism indicator with potential transformer, secondaries grounded.

As the iron vane is attracted or repelled by the rotating field, it takes up a position where the zero of the rotating field occurs at the same instant as the zero of its own field. In the single phase meter the positions of voltage and current coils are interchanged and the rotating field is produced by means of a split phase winding, connected to the voltage circuit.

The method is that of *the split phase bipolar synchronous motor with separate alternating current excitation.*

NOTE.—*The principle of operation* of the rotating field type, synchronism indicator is the same as that of the power factor meter, accordingly a detailed description of how they measure phase angle differences would only be a repetition of that section. The only difference lies in the winding of the internal coil which magnetizes the iron vane. This is wound with a large number of turns of fine wire, and is connected in series with a resistor, directly across the voltage of the machine being synchronized. The lower terminals are connected to the bus bar, and consequently, the magnetic axes of the rotating field rotate in synchronism with the bus bar, while the magnetism in the iron vane is in phase with the voltage of the machine being synchronized (incoming machine).

Phase displacement is accomplished by a reactor and a resistor both mounted externally.

The motor field is energized by a single phase current from one of the machines to be synchronized (the running machine) and its armature from the other (the starting machine).

Since the armature coils are nearly perpendicular to each other and as one is connected to the reactor and one to the resistor, a rotating field is generated in the armature with the alternating of the current in the stationary field.

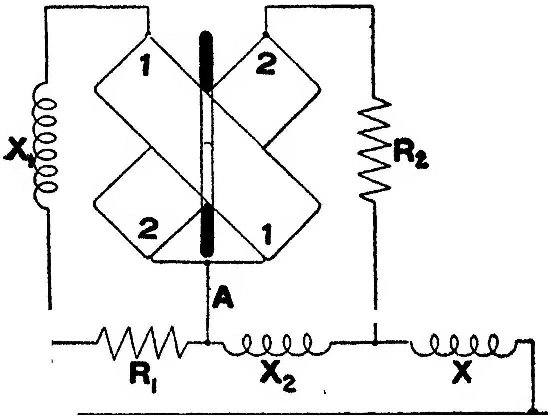


FIG. 4,552.—Diagram of Weston induction type frequency meter connections. The coils are connected in series across the line, with a reactor in series with one and a resistor in series with the other. A resistor is connected in parallel with one coil and the reactor, and a reactor is connected in parallel with the other coil and the resistor; then the whole combination is connected in series with a reactor, the purpose of which is to damp out the higher harmonics. The circuits, as shown, form a Wheatstone bridge, which is balanced at normal frequency. An increase in frequency will increase the reactance of the reactors and thus upset the balance of the bridge, allowing more current through one coil and less through the other.

The armature tends to assume a position where the field set up in the armature coincides with the alternating field in the stator when the latter passes through its maximum intensity. The armature and the pointer attached to the armature shaft will therefore move forward or backward at a speed corresponding to the difference in the frequency of the two machines.

When the machines are running at the same frequency (the same speed if both machines have the same number of poles) the pointer will become stationary, and its position when stationary will depend upon the phase

relation existing between the two machines. Coincidence in phase is shown when the pointer remains stationary in the vertical position at the marked point at the top of the dial. The machine should be "thrown in" when this position is indicated. A complete revolution of the pointer indicates a gain or loss of one cycle in the starting machine.

Frequency Meters.—A frequency meter or indicator is an

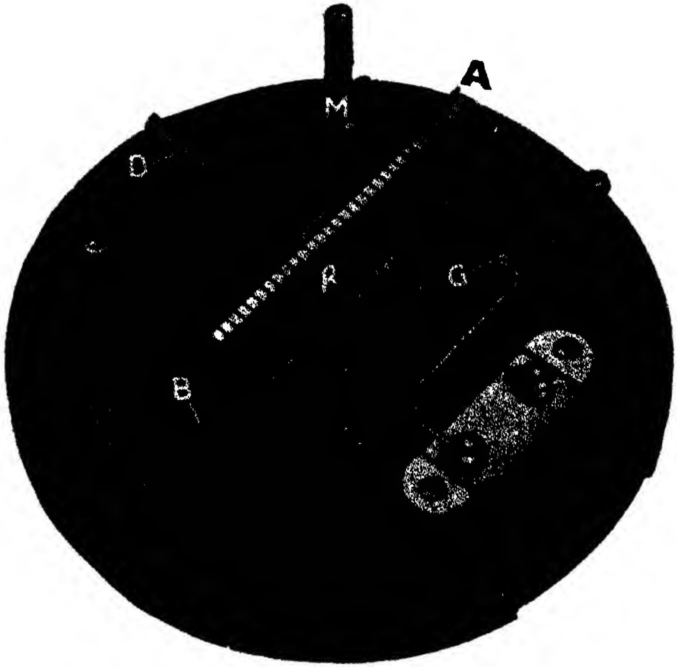
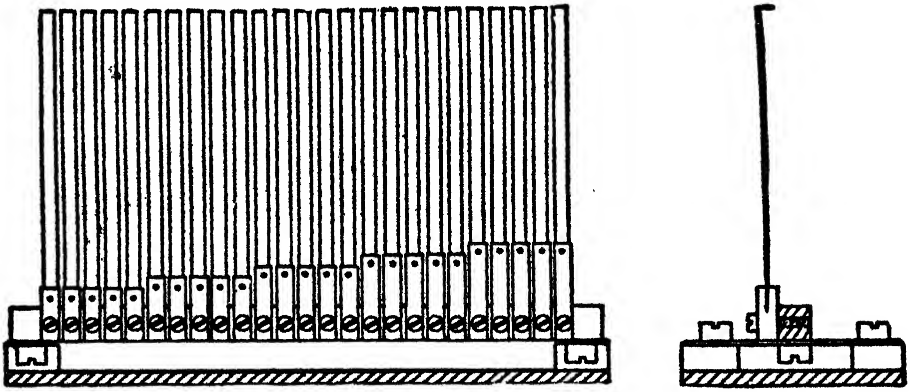


FIG. 4,553.—Interior view of Frahm vibrating reed frequency meter. Frequency indication is obtained from the vibration of certain units in a row of tuned steel reeds, visible through an oblong opening in the scale plate of the instrument. The principle underlying the construction is that of resonance, subjected to rhythmic impulses of the same frequency as the natural period of vibration of the body itself. *The parts are:* A, armature of the electro-magnet M; B, bridge piece on which are mounted the reeds R, armature A, also is mounted on B; D, amplitude adjusting screw by which the air gap between A and M, is set; G, protective series resistance for M; M, electro-magnet; R, tuned reeds, each one of which is adjusted to respond by resonance to a given mechanical vibration set up in B, through A, by the alternating current in M. *In construction,* a number of reeds R, each about ⅛ in. wide, consisting of special spring steel, carefully tempered and nickel plated, are screwed in a row to a bridge piece B, to which is attached the armature A, of a small electro-magnet M, mounted close to it. When the instrument is connected across the circuit the frequency of which is to be measured, the current, after passing through a series resistance G, excites the electro-magnet which thus imparts to the armature A, *one* impulse for each cycle of current if the core of the electro-magnet is a permanent magnet, and *two* impulses for each cycle of

instrument used *for determining the frequency, or number of cycles per second of an alternating current.*

There are several forms of frequency indicator, whose principle of operation differs, and according to which, they may be classed as

1. Synchronous motor type;
2. Resonance type;
3. Induction type.



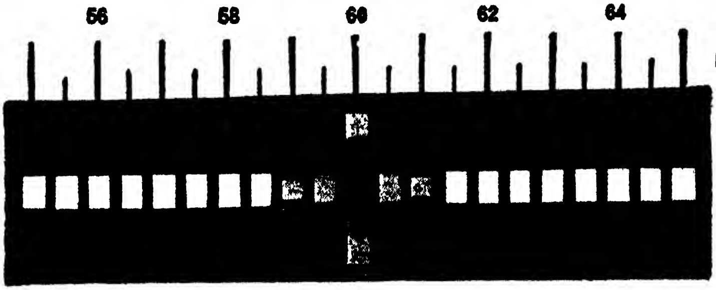
FIGS. 4,554 and 4,555.—Side and end views of Frahm resonance type frequency meter reed Owing to the principle employed in the meter it is evident that the indications are ind pendent of the voltage, change ot wave form, and external magnetic fields.

Synchronous Motor Type.-

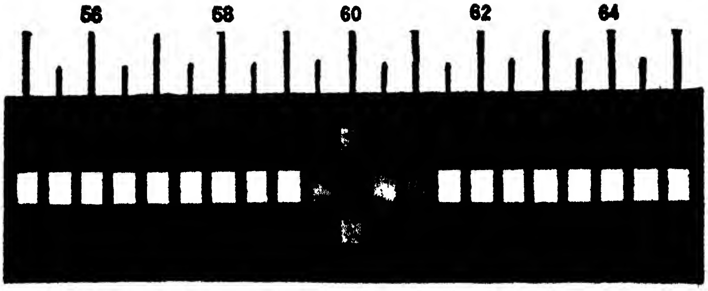
In this type a small synchronous motor is connected in the circuit of the current whose frequency is to be measured. After determining the

FIG. 4,553.—*Text Continued.*

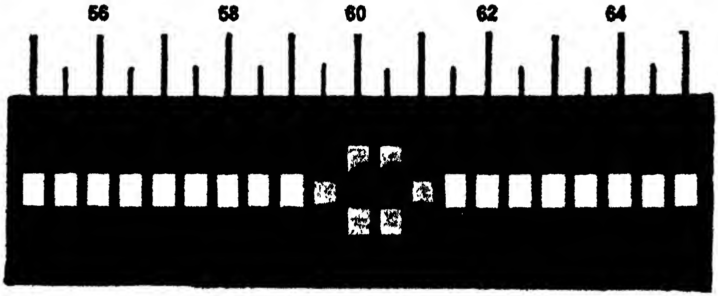
current if the core of the electro-magnet is of soft iron. The vibration of the armature A, is transmitted to the reeds R, and just as one tuning fork will respond to another having the same period of vibration, so will that reed which is in tune with the frequency of vibration of the armature, at once respond vigorously. The scale at the point opposite this reed is marked with the number of cycles per second of the alternating current, and hence the frequency is clearly indicated. In order to give a clear indication, the reeds have a small portion of their upper ends bent over at right angles and enamelled white, so as to make them conspicuous against the black interior of the instrument.



READING = 60.0



READING = 60.1



READING = 60.25

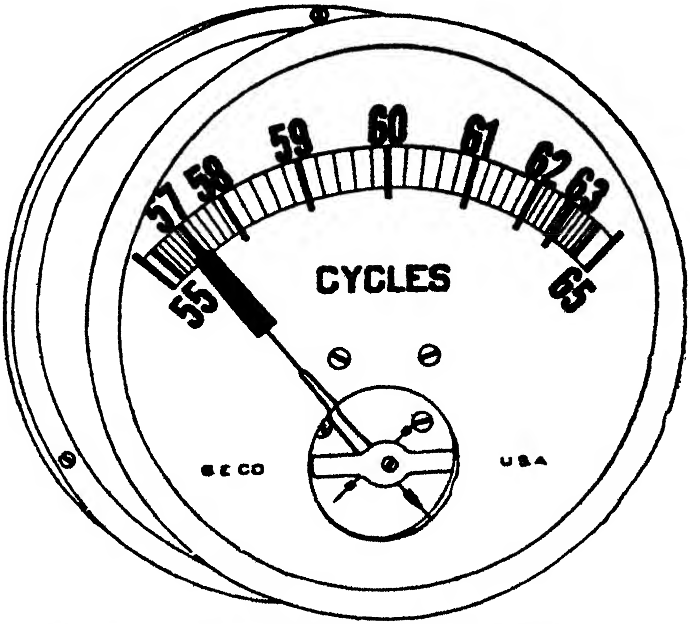
4,556 to 4,558.—How to read a Frahm frequency meter. Vibration begins at about 2% below the exact value to which the reed is tuned, reaches its maximum at the exact value and extends to about 2% above that value. Therefore more than one reed usually is in motion and from the respective lengths of the banks formed by the vibrating reeds across the scale opening the exact value of the frequency may be estimated down to one-fourth of the interval between successive reeds. On the upper scale the reading is very evidently 60. On the lower scale, the reeds indicating 60 and 60.5 are vibrating equally, so that the reading is *half way* between these two values, that is 60.25. Referring to the middle scale, it will be seen that the reed indicating 60 is vibrating more than any other, so that the reading is therefore nearer to 60 than to any other scale division. Furthermore, the reed indicating 60.5 is in next greatest vibration, so that the reading is again between 60 and 60.5. However, the reed indicating 60 is vibrating with an amplitude about three times that of the reed indicating 60.5, so the reading is now one-quarter way from 60 toward 60.5 instead of one-half way. That is, the reading is $60\frac{1}{8}$ or approximately 60.1.

revolutions per minute by using a revolution counter, the frequency is easily calculated as follows:

frequency = (*revolutions per second* × *number of poles*) ÷ 2.

Resonance Type.—

In construction the resonance type consists of ***a pendulum, or reea, of given length, which responds to periodic forces having the same natural period as itself.***



. 4,559.—General Electric resonant circuit type frequency meter.

The instrument comprises a number of reeds of different lengths, mounted in a row, and all simultaneously subjected to the oscillatory attraction of an electro-magnet excited by the supply current that is being measured. The reed, which has the same natural time period as the current, will vibrate, while the others will remain practically at rest.

The construction and operation of the instrument may be better understood from figs. 4,554 and 4,555, which illustrate the indicating part of the Frahm meter. This consists of one or more rows of tuned reeds rigidly mounted side by side on a common and slightly flexible base.

The reeds are made of spring steel, 3 or 7 mm. wide, with a small portion of their free ends bent over at right angles as shown in fig. 4,555 and enameled white so that when viewed end on they will be easily visible. The reeds are of adjustable length, and are weighted at the end.

A piece of soft iron, rigidly fastened on the base plate which supports the reeds, forms the armature of a magnet.

When the magnet is excited by alternating current, or interrupted direct current, the armature is set in vibration, and that gives a slight movement to the base plate at right angles to its axis, thereby affecting

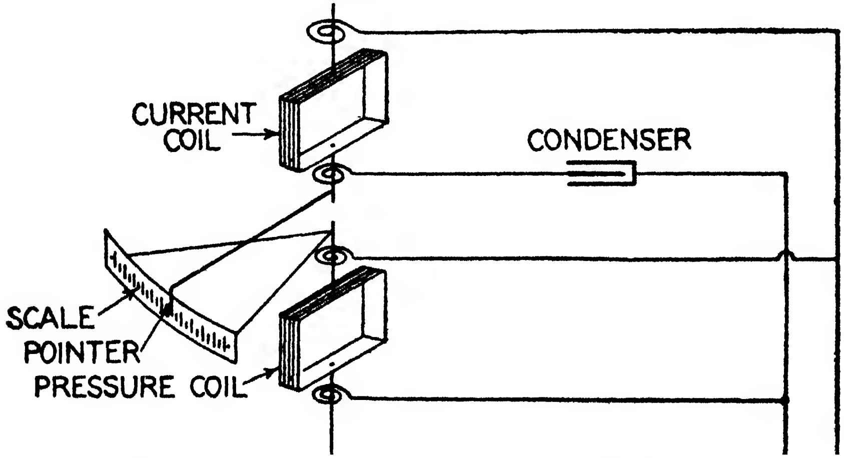


FIG. 4,560.—Langsdorf and Gegole frequency meter. The operation of this meter is based on the fact that if an alternating pressure of E volts be impressed on a condenser of capacity C, in farads, the current in amperes will be equal to $2\pi\sim EC$, provided the pressure be constant. *In construction*, the scale is mounted on the same axis as the pressure coil, across the mains so as to render the instrument independent of variation of voltage. For a discussion of this meter, see *Electrical Review*, vol. LVIII, page 114.

all the reeds, especially those which are almost in tune with its vibrations.

The reed which is in tune will vibrate through an arc of considerable amplitude, and so indicate the frequency of the exciting current.

The resonance type is used for laboratory work.

Induction Type.—

This form of frequency meter consists of *two volt meter electro-magnets acting in opposition on a disc attached to the pointer shaft.*

One of the magnets is in series with an inductance, and the other with a resistance, so that any change in the frequency will unbalance the forces

acting on the shaft and cause the pointer to assume a new position, when the forces are again balanced.

The aluminum disc is so arranged that when the shaft turns in one direction the torque of the magnet tending to rotate it decreases, while the torque of the other magnet increases. The pointer therefore comes to rest when the torques of the two magnets are equal, the pointer indicating the frequency on the scale.

An object of the aluminum disc is to damp the oscillations of the pointer.

Surge Indicator or Klydonograph.—There is plenty of evidence

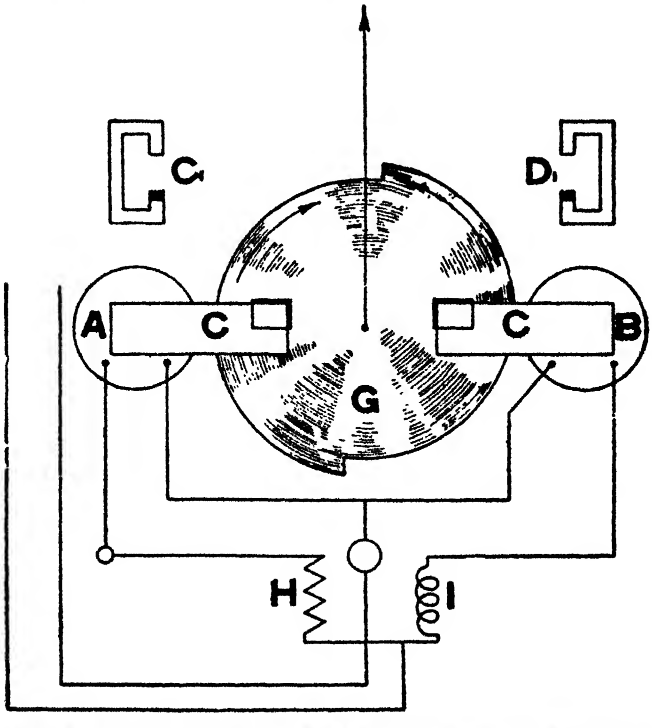
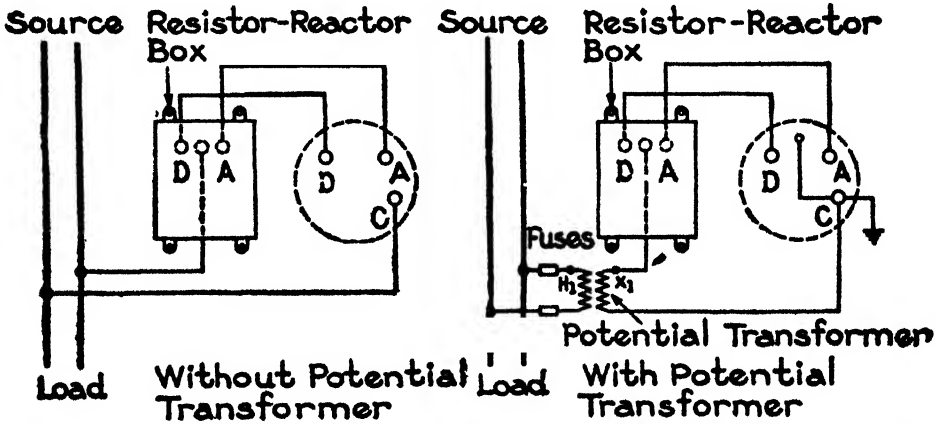


FIG. 4,561.—*Elements of induction type frequency meter* illustrating principle of action. The actuating force consists of two induction volt meter elements, A and B. These act on a disc G, and tend to move the disc and the pointer shaft in opposite directions. One of the elements is in series with a resistor H, and the other is in series with a reactor I, so that any change in the frequency tends to change the relative strength of the two elements and cause rotation. The disc is so shaped that as it moves, the amount of its metal under the stronger element becomes less than that under the weaker element, so that with every relation between the two electro-magnet strengths there is some point where the torques produced by the two elements balance and the pointer comes to rest.

that surges of considerable magnitude appear on extensive transmission systems and it is undoubtedly desirable that detailed information concerning them be obtained.

From what data are available it is rather evident that many surges of very high value exist which have an extremely short duration. Practically all data concerning these surges have been obtained by the use of spark gaps in some form or other. It has been assumed that a sphere spark gap can be made to



FIGS. 4,562 and 4,563.—Connections for General Electric resistor reactor frequency meter, and for resonant circuit type frequency meter. A rheostat is placed on one side of the resistance box of the resistor reactor type meter. This rheostat is used to adjust the instrument for the characteristics of the circuit to which it is connected. When first installed, the arms on the side of the box should be moved until the needle of the instrument indicates the frequency as determined by a stop watch and speed counter. Screws are provided to prevent accidental movement of the arms, after this adjustment has once been made. When the two arms are farthest apart, the resistance is cut out; bringing them together puts resistance in the circuit, the amount of which varies with the position of the arms. No change of the rheostat will be necessary after the adjustment has once been made, as the accuracy is not affected by variation of the load in a given machine.

have practically zero time lag of break down and it has been used as a standard in determining the duration of these surges.

A sphere spark gap has a considerable time lag where the voltage in excess of its flashover value is comparatively small.

The object in the development of the surge indicator is to provide some means that will record voltages, whether of extremely short duration or not, and to produce a graphic record of detailed information concerning

the surges, such as polarity, magnitude, steepness of application, etc. This instrument is based on an old principle that was first observed in 1777 by Dr. Lichtenburg and makes use of figures known as Lichtenburg figures. Dr. Lichtenburg found that on discharging a condenser such as a Leyden jar across a spark gap onto a terminal in contact with an insulating plate placed between this terminal and a ground plate, and then sprinkling powder on the plate, the powder would arrange itself in the form of a figure of a very peculiar appearance.

By using powders of different colors beautiful figures could be produced, the figure produced by a positive charge being entirely different from that produced by a negative charge.

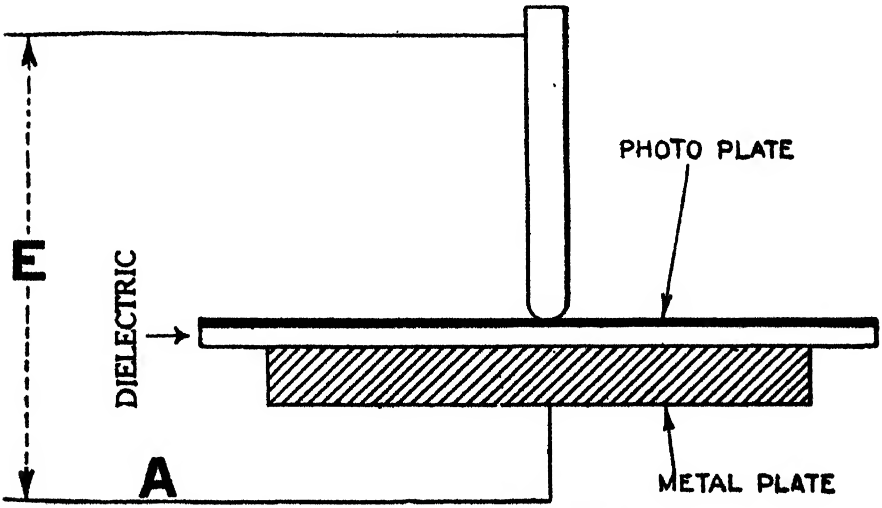
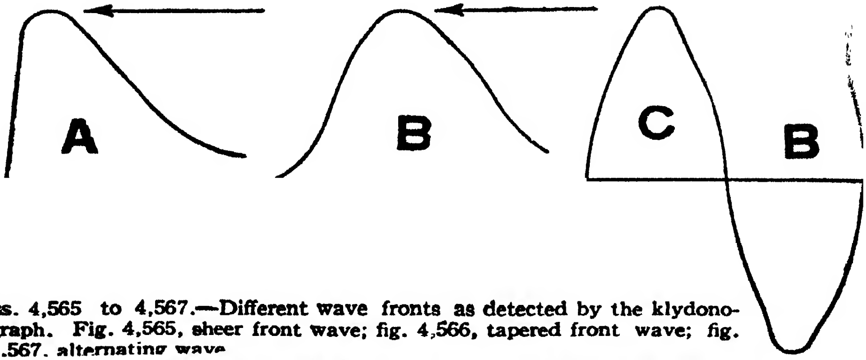


FIG. 4,564.—Elements of the klydonograph or surge indicator.

In 1888 J. Brown and E. Trowvelot found that on replacing the insulating plate with a sensitized photographic plate, the emulsion being in contact with the terminal, and developing the plate, figures very similar to those produced by Lichtenburg were found. Since Dr. Lichtenburg's time the Lichtenburg figures have been studied by many investigators. The most recent study was a very complete exposition of these figures given by P. O. Pederson.

Apparently very little is known about the actual cause of the Lichtenburg figure on photographic plates, although many investigators have attempted an explanation of this phenomenon. The elements of a surge indicator in its simplest form are shown in fig. 4,564. The photographic plate, of course, must be placed in a dark box.



Figs. 4,565 to 4,567.—Different wave fronts as detected by the klydonograph. Fig. 4,565, sheer front wave; fig. 4,566, tapered front wave; fig. 4,567, alternating wave.

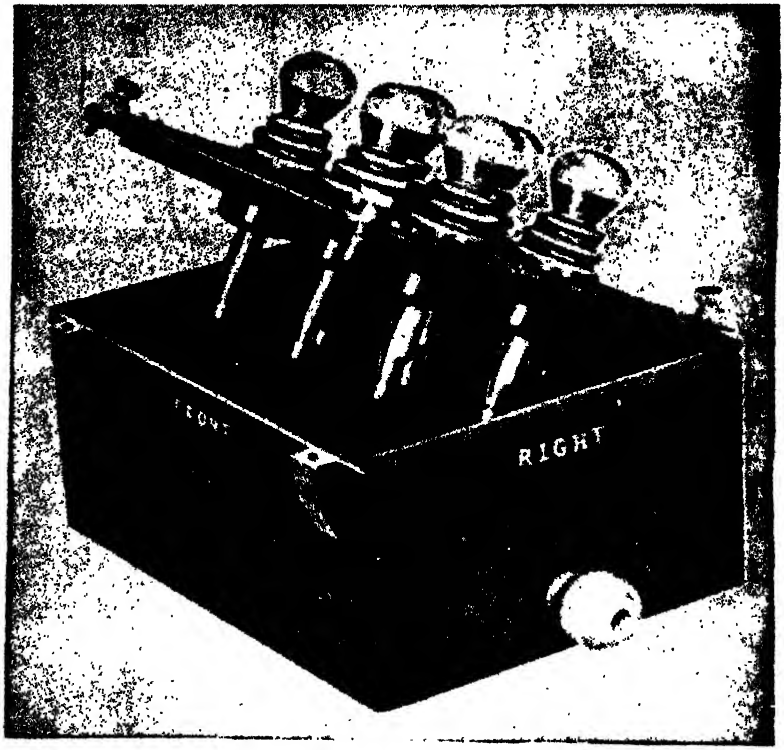
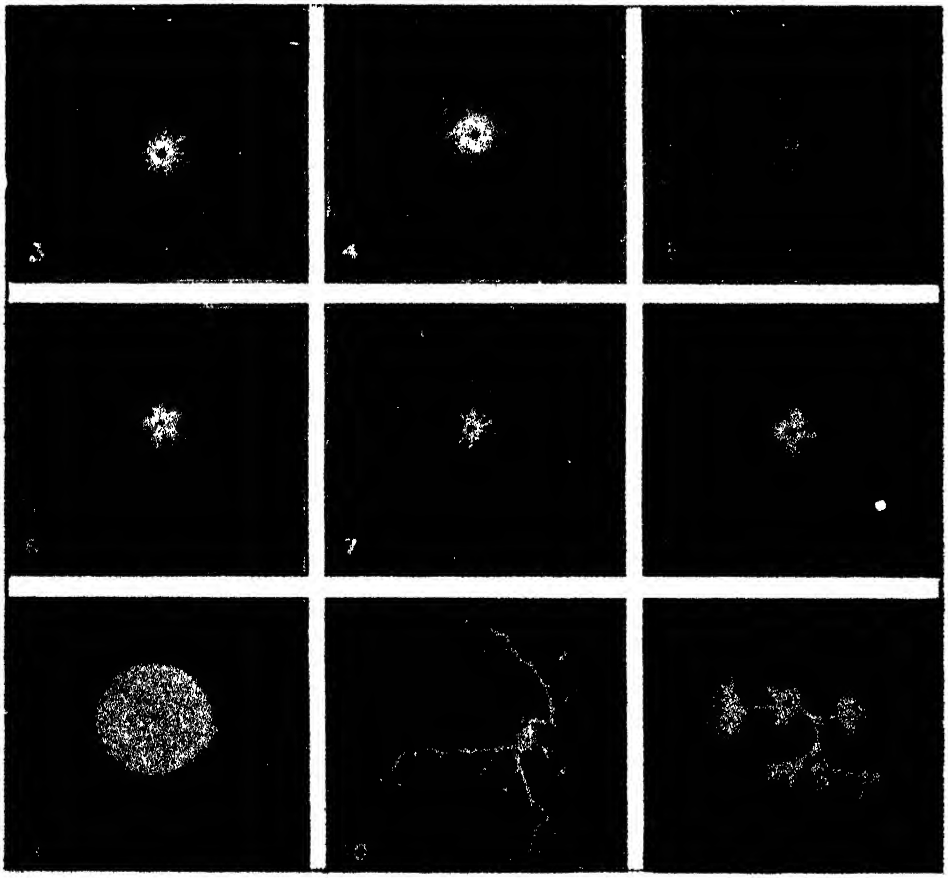


Fig. 4,568.—Type of klydonograph used to record the surges shown in the accompanying illustrations.

If a voltage be impressed between the terminal and ground plate, as at E, on developing the photographic plate figures will appear that will give pertinent information concerning the nature of the voltage impressed. If the voltage be in the form of a surge, that is, uni-directional, either with a sheer front as indicated in fig. 4,565, or tapered front, as in fig. 4,566, the figure on the photographic plate will differentiate between the tapered front and the abrupt front, and it will also indicate whether the surge was of positive or of negative polarity.



FIGS. 4,569 to 4,577.—Klydonograph records of various surges. No. 3, positive surge with an abrupt front; No. 4, negative surge with a steep front; No. 5, a surge of a wave similar to fig. 4,566, with a 5 microsecond front; No. 6, negative surge with a 5 microsecond front; No. 7, positive surge with a 200 microsecond front; No. 8, negative surge with a 200 microsecond front; No. 9, 60 cycle alternating voltage; No. 10, positive surge above the working range of the instrument; No. 11, negative surge occurring above the working range of the instrument.

Again, if the surge be alternating, as in fig. 4,567, the figure will differentiate between it and the uni-directional surges. A wave with a 5 microsecond front requires five millionths of a second for the voltage to rise to its full value. Expressed in terms of a traveling wave on a transmission line, this 5 microsecond front would represent a taper extending over one mile of transmission line.

A wave with a 40 microsecond front would correspond to a taper of 40 miles of a transmission line. In case the voltages are higher than those represented by figs. 4,576 and 4,577 a spark will occur and fog the plate.

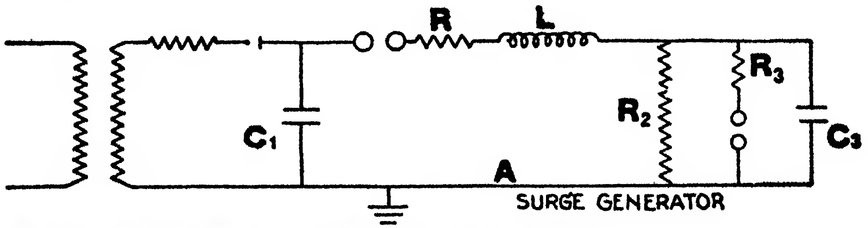


FIG. 4,578.—Network used to produce surges in the laboratory.

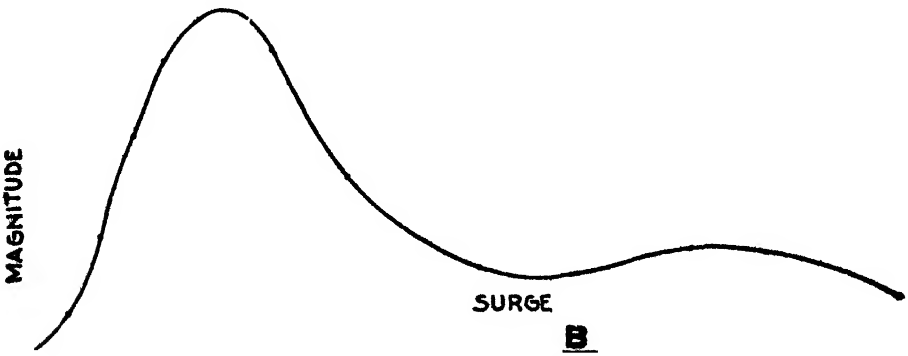


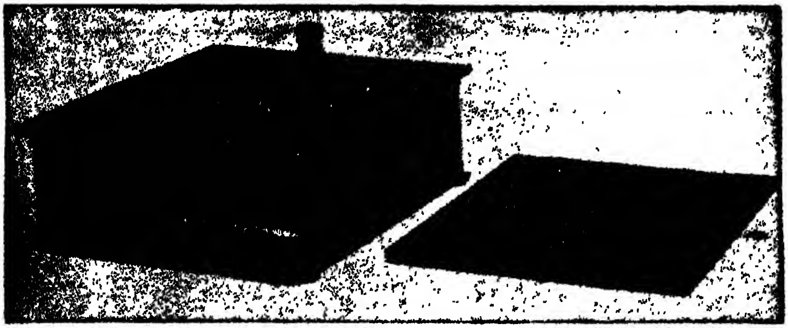
FIG. 4,579.—Typical surge produced by the network of fig. 4,578.

It is interesting to note that the positive and negative surges maintain a decided difference in appearance right up to the point where a spark occurs. Fig. 4,568 shows the klydonograph that was used in obtaining all of the figures shown and is a convenient form for certain kinds of laboratory work. It is not suitable, however, for graphic work.

Figs. 4,578 and 4,579 show network used in the laboratory and typical surge produced by it. The diameters of the figures give a measure of the magnitude of the surges. The positive and negative figures have different

calibrations, the figure for positive surge being considerably larger than that for the negative surge of the same magnitude.

Ground Detectors.—Instruments of this name are used for detecting (and sometimes measuring) the leakage to earth or



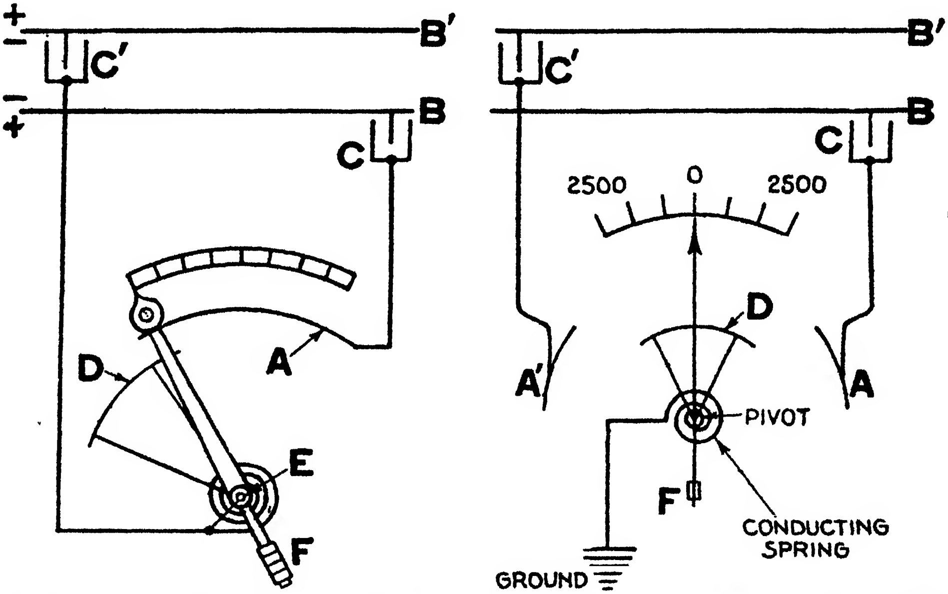
FIGS. 4,580 and 4,581.—Experimental recording type of klydonograph.

the insulation of a line or network and are sometimes called *ground or earth indicators, or leakage detectors.*

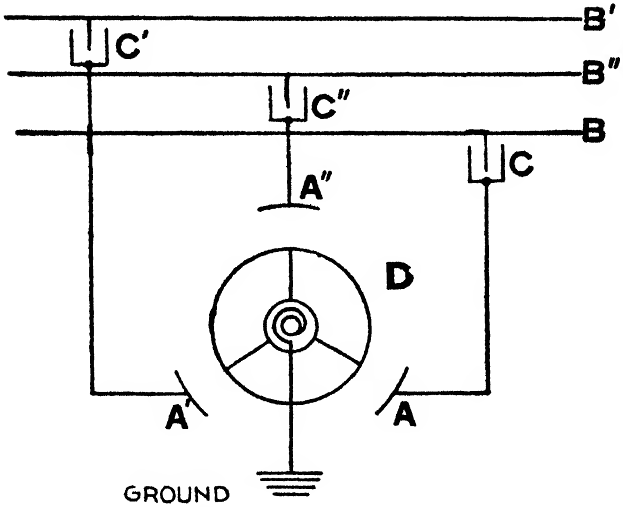
For systems not permanently earthed anywhere, these instruments are nearly all based on a measurement of the pressure difference between each pole and earth, two measurements being required for two wire systems, and three for three wire, whether direct current single phase, or polyphase alternating current. ***In the case of direct current*** systems, the insulation, both of the network and of the individual lines, can be calculated from the readings, ***but with alternating current,*** the disturbance due to capacity effect is usually too great. ***In any case,*** however, the main showing the smallest pressure difference to earth must be taken as being the worst insulated.

For low tension systems ***moving coil*** (*for alternating current*) or ***moving iron*** instruments (*for direct current*) are the most used. while for high

tension systems electrostatic volt meters are to be preferred. ***On systems having some point permanently earthed*** at the station, as for instance the *neutral wire* of a direct current system, or the neutral point of a three phase system, an ammeter connected in the *earth wire* will serve as a rough guide. It should indicate no current so long as the insulation is in a satisfactory state, but on the occurrence of an earth it will at once show a deflection. The indications are, however, often misleading and serve more as a warning than anything else.



FIGS. 4,582 and 4,583.—***Elements of electrostatic type of volt meter and single phase ground detector*** illustrating principle of operation. These instruments depend for their operation on the attraction between a statically charged stationary vane and an oppositely charged, and suitably pivoted moving vane. In the static volt meter fig. 4,582, the stationary vane A, is charged with the polarity of line B, through the condenser C, while the movable vane D (pivoted at E,), is charged with the polarity of line B′, through the condenser C′. The vane A, is so shaped and spaced from the vane D, that when it is charged, it tends to attract the vane D, to the extreme right hand side. This attraction is opposed both by the counter weight F, and a weak spiral control spring. Therefore, its deflection becomes a measure of the voltage applied to the condensers C and C′, and is indicated on a suitably graduated scale. In the single phase ground detector, two stationary vanes are used, both acting on one moving vane, so that in case of thoroughly insulated lines, there is no deflection. Referring to fig. 4,583, the stationary vanes are represented by A and A′, connected through condensers C and C′, to lines B and B′. Assuming the charges on A and A′, to be equal, the pointer indicates zero. If a ground occur on line B, the charge on A, is weakened, thus permitting the charge on A′, to draw the moving element more within its influence against the action of the counter weight F, and the controlling spring. The deflection depends upon the extent of the ground on B. The pointer always indicates away from the grounded line.



F'ıı 4,584.—Elements of three phase electrostatic ground detector. In this three phase instrument the moving vane is a spheroid, or part of a spherical shell, and is mounted on a universal joint, having a vertical and horizontal shaft, permitting the element to deflect in any direction. Each shaft has a spiral control spring which holds the vane normally in center position. A suitable counter-weight balances the weight of the vane. There are three stationary vanes provided, each connected to its respective phase by means of a suitable condenser. There is no scale marked on the three phase instrument, but grounds show up by indicating various positions marked on the glass. A, A', and A'' represent the three stationary vanes connected to the three phase lines, B, B' and B'', through condensers C, C' and C''. The movable vane D, is permanently grounded. Assuming no grounds on the lines, the charges A, A' and A'', attract the vane D, equally, and consequently it stays in the center, its position being indicated by a black dot in the center of the vane, which is visible through the circle painted on the glass. If a ground occur on line B, the static charge on the vane A, is weakened, and as vanes A' and A'' pull equally, the vane is deflected midway under vanes A' and A''. Likewise, grounds on either of the other lines will cause a deflection away from the grounded lines. Two grounded lines, which should cause deflection toward the ungrounded line, if great enough to cause deflection will generally be manifested by excessive current and damage at the points of ground.

NOTE.—*The advisability* of using a ground detector depends to a large extent on the operating conditions of the circuit. In systems where the voltage is high and there is large electrostatic capacity, as is the case in conduit distributing systems in large cities, or, in general where there is large electrostatic charging current, a partial ground has the same effect as a violent short circuit and causes sufficient destructive effect to transmit the trouble to other conductors. In some large overhead distributing systems, the total leakage under normal operating conditions, especially in wet weather, is sufficient to indicate grounds. It is obvious that in all such cases nothing is gained by installing a ground detector. As a rule, on any system in which one conductor might become grounded without this fact being made evident by the tripping of circuit breakers or a similar result, the use of ground detectors is recommended. If the conditions be such that a ground on one conductor immediately manifests itself in some positive manner without reference to the ground detector, such an instrument is superfluous. This practically limits the application of ground detectors to overhead lines which do not have a grounded neutral and to comparatively small underground systems.

FIG. 4,585.—Westinghouse ground detector with one vane removed to show movement.

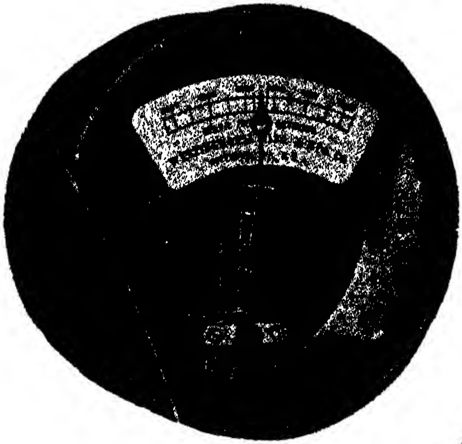


FIG. 4,586.—Westinghouse single phase ground detector.

FIG. 4,587.—Westin. house three phase static ground detector.

NOTE.—*On high tension circuits* no other than the electrostatic type of ground detector is practicable where indications which are at all sensitive are required. To connect other types of instruments to the primary in series with their necessary resistances would consume an excessive amount of energy and produce dangerous conditions at the switchboard, while ground detecting volt meters connected to the secondaries of transformers are not at all sensitive. The electrostatic ground detectors are connected to the circuit through condensers, and are both sensitive and economical.

Meter Connections

In the preceding chapters, the fundamental construction principles of meters most commonly employed in power measurements have been fully treated. The type of meters usually employed for measurement of voltage, current and power are:

1. The voltmeter;
2. The ammeter;
3. The wattmeter;
4. The power factor indicator.

Meters employed for measurement of power are the *wattmeter*, and that for power factor, the *power factor meter* or *indicator* as it is usually termed.

It is the purpose of this chapter to illustrate the general principles of connections as applied to the aforementioned meters.

In connection of meters the relative location of the elements in the meter and the connection of the phase wires may differ from that shown in the diagrams, depending upon the convention and the type of meter used. Also, when any question arises on the use of a specific meter or instrument, it is recommended that the information be obtained from the manufacturer. Any request for information on instruments should be complete with all the information shown on the instrument

nameplate, that is, its rating, serial number, when the instrument was purchased, and a description of the special conditions under which the instrument is used.

Definitions.—The terms *meter* and *instrument* are used alternately to designate a certain device such as an *ammeter, voltmeter, wattmeter,* etc. By definition, an instrument is a device for measuring the present value of a quantity under observation. An instrument may be an indicating instrument or a recording instrument.

The term "instrument" is used in two different senses; (*a*) instrument proper and (*b*) to include not only the instrument proper, but in addition, any necessary auxiliary device such as shunts, shunt leads, resistors, reactors, capacitors or instrument transformers.

The term meter is also used in a general sense to designate any type of measuring device including all types of electric measuring instruments.

Ammeter Connections.—An ammeter should always be connected in *series* with the load—never *across* it. When an ammeter is connected to a current transformer, the current transformer secondary should be grounded.

Make certain that the meter is of sufficient capacity to measure the current flowing through the wire or conductor whose current it is desired to measure. Check the current transformer ratio, and the shunt resistance to be used in each instance, with the scale range of the meter to insure a suitable pointer deflection before the current is sent through it.

When it is desired to use a direct current instrument to measure the current flowing in an alternating current circuit, a rectifier must be used.

Whenever a shunt is used with a milli-voltmeter to read current, always check to make certain the leads with which the instrument was calibrated are being used.

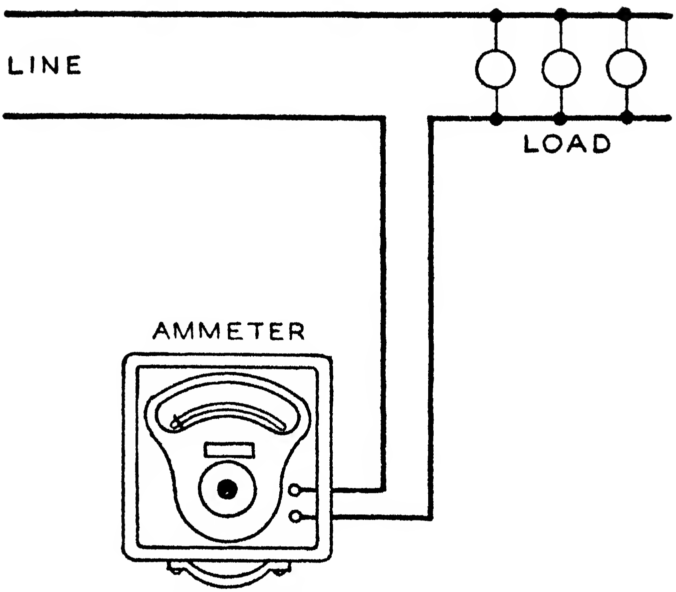


Fig. 4587-1.—Typical ammeter connection for *a.c.* measurement.

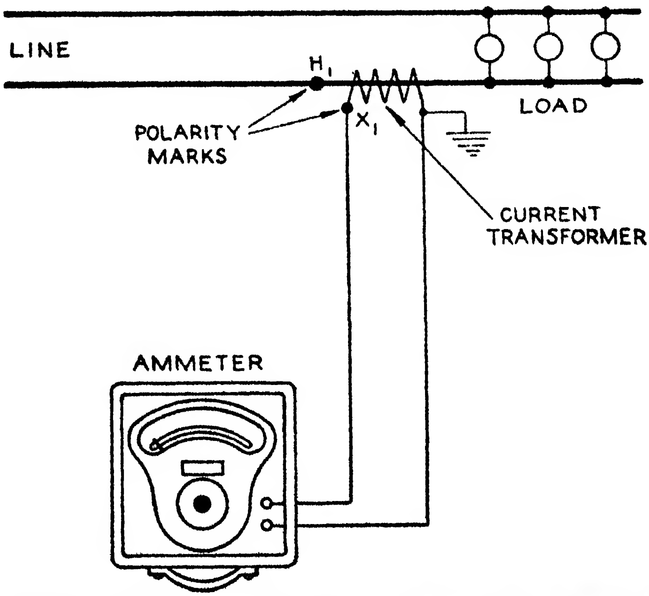


Fig. 4587-2.—Typical ammeter connection for *a.c.* measurement when used with current transformer.

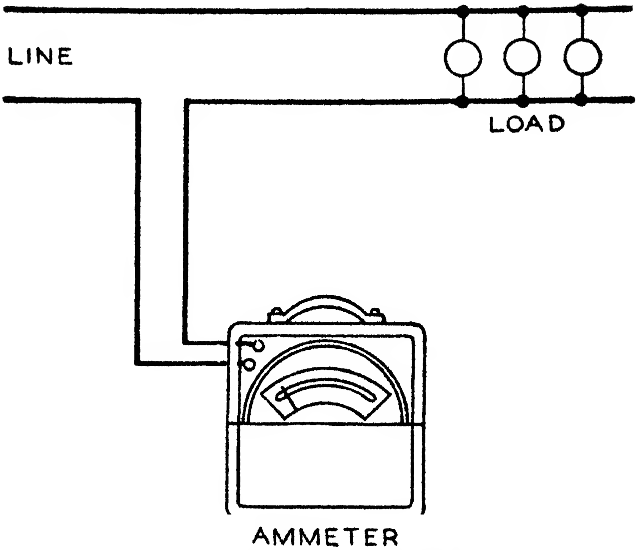


Fig. 4587-3.—Typical ammeter connection for *d.c.* measurement.

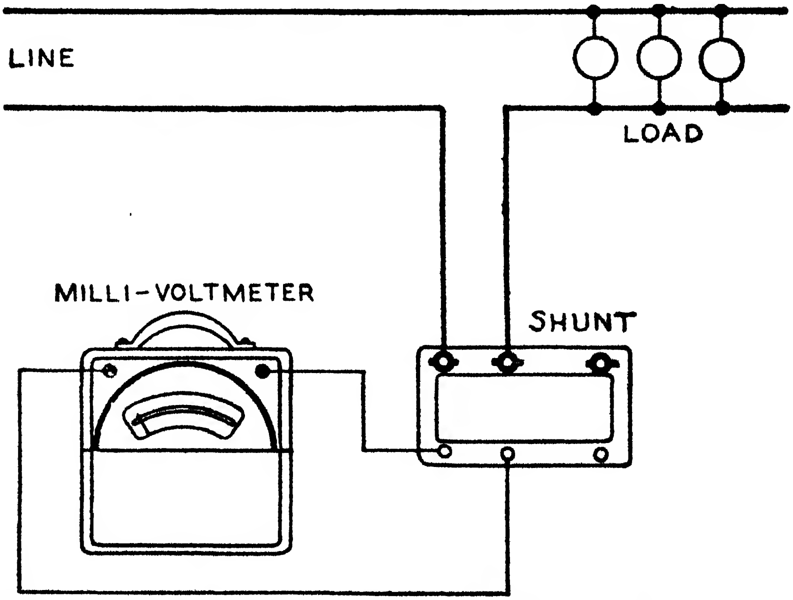


Fig. 4587-4.—Typical connection of *d.c.* milli-voltmeter and shunt when used for of current. Shunts are frequently used with milli-voltmeters for measurements of large currents. If the instrument reads backwards, reverse the instrument leads.

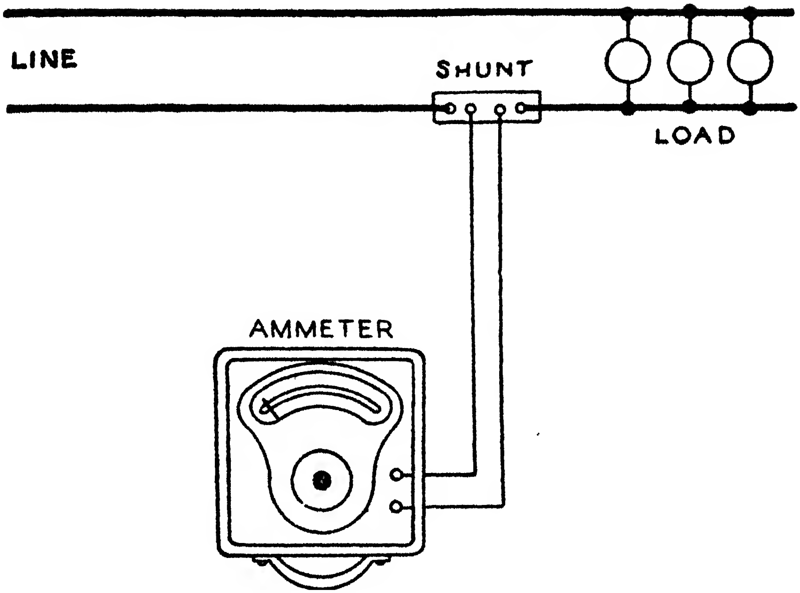


FIG. 4587-5.—Typical *d.c.* ammeter connections when used with shunt.

Voltmeter Connections.—A voltmeter should always be connected *across* the load—never in *series* with it. When a voltmeter is connected to a potential transformer, the potential transformer secondary should be grounded.

To extend the range of a voltmeter, a multiplier may be used. If a higher rated voltmeter is not available, use a potential transformer.

When external resistance multipliers are used, check both the serial number of the instrument and that of the multiplier to make certain of the correct combination.

When a potential transformer is to be used, always make sure that the instrument is connected to the secondary or low voltage side. Make certain that the voltmeter leads are properly insulated for the voltage that is to be measured.

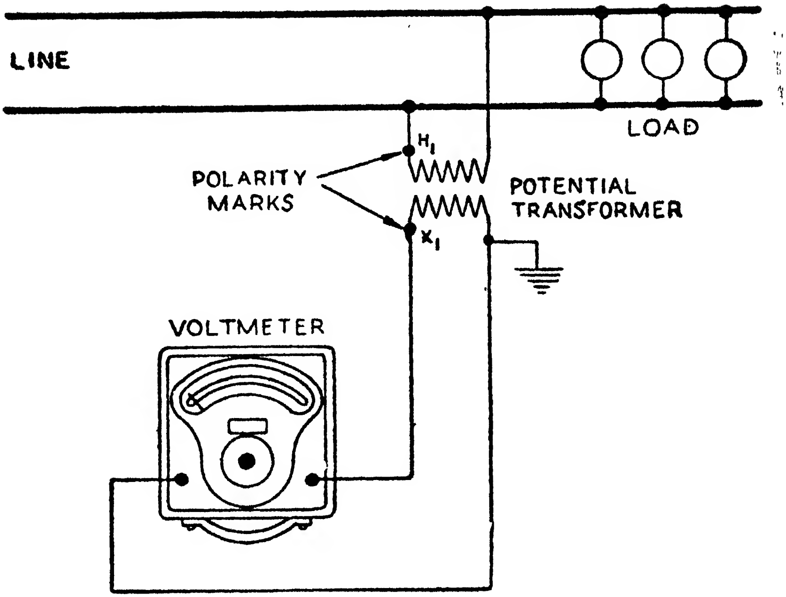


FIG. 4587-6.—Typical voltmeter connection for *a.c.* measurement when used with potential transformer.

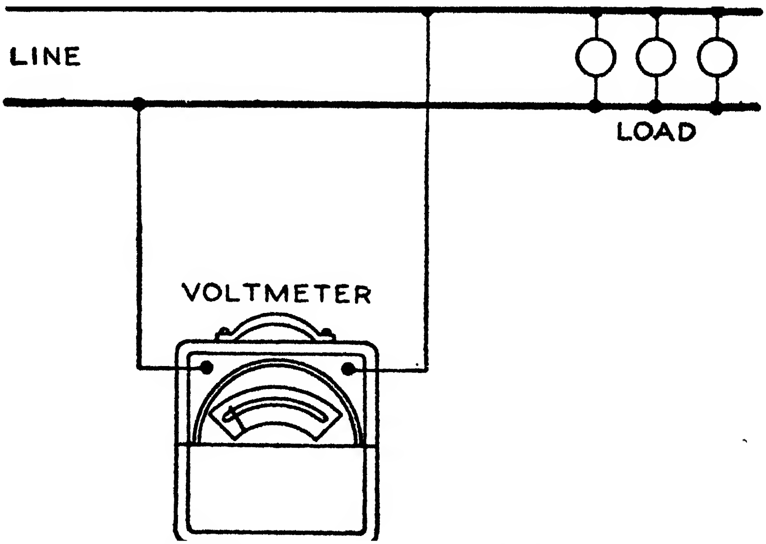


FIG. 4587-7.—Typical voltmeter connection. If the instrument reads backwards, reverse the instrument leads.

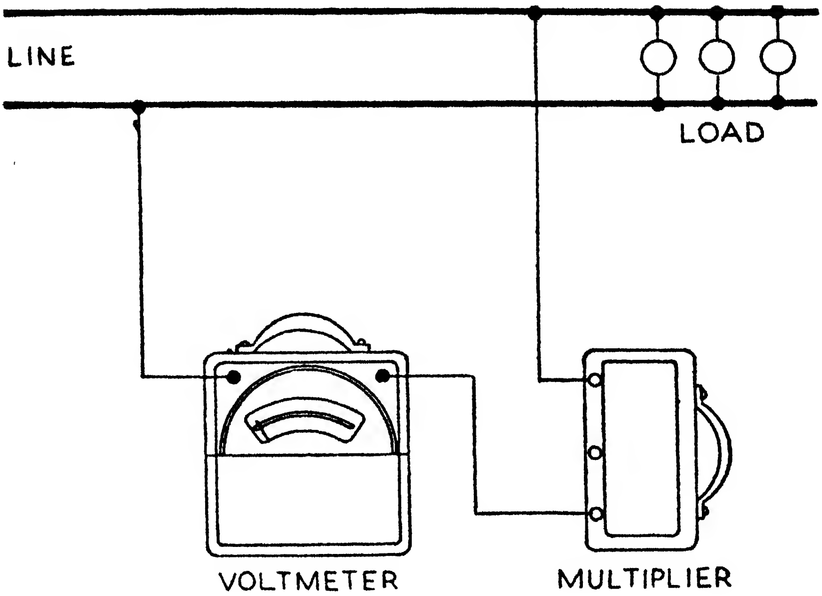


FIG. 4587-8.—Typical voltmeter connection when used with multiplier.

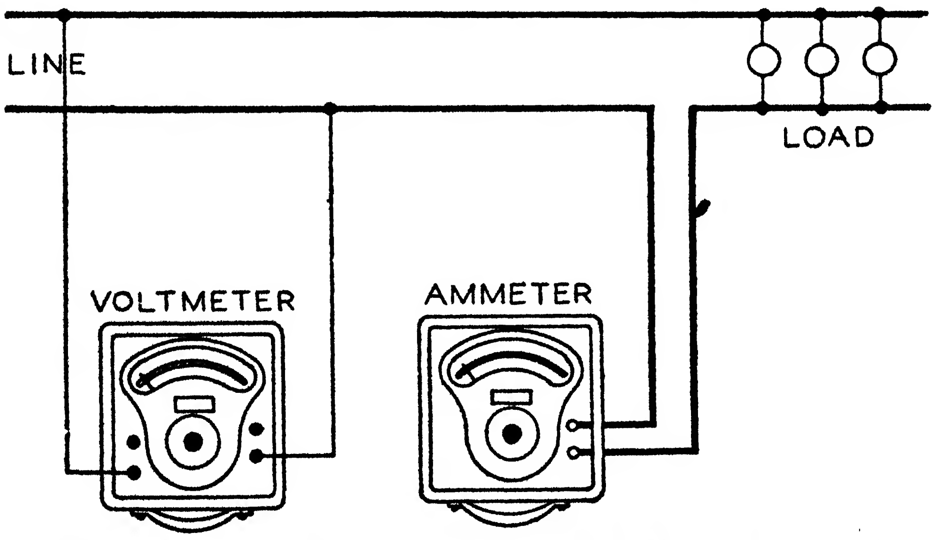


FIG. 4587-9.—Typical connection diagram of voltmeter and ammeter in a single phase circuit. When the instruments are connected as shown, the voltmeter measures *line voltage, not load voltage*. The ammeter measures *load current only*.

Volt and Ammeter Connections.—Since in a unidirectional current, power is the product of voltage and current, the power taken by a certain load may be obtained by connecting the meters as shown in figs. 4,587-9 and 4,587-10.

Wattmeter Connections.—Instead of using two separate instruments, however, to measure the power consumed by the load, it is customary to use a single instrument called a *wattmeter*. Wattmeters are provided with scales, usually graduated in watts or kilowatts.

A wattmeter is an instrument containing within itself two elements, one having an ammeter part of *low* resistance to measure the *current* and a voltmeter part of *high* resistance for measurement of the *voltage*.

The indicator shows the product of the volts times the amperes, that is, the *watts*.

A wattmeter, therefore, usually has four terminals, two for the ammeter leads and two for the voltmeter leads. The utmost care must, however, be exercised to use the proper terminals, as an error in this respect may ruin a very valuable instrument.

Figs. 4,587-11 to 4,587-23 show the methods of connections under various conditions of service. When the wattmeter is used with both voltmeter and ammeter, the ammeter terminals are connected in series with the load whose power it is desired to measure, whereas, the voltmeter terminals are connected across the load.

Potential transformers are recommended on circuits having a potential above 300 volts. On circuits of 750 volts and above, potential and current transformers should be used.

When a wattmeter is used with current and potential transformers, the transformers secondary should always be grounded.

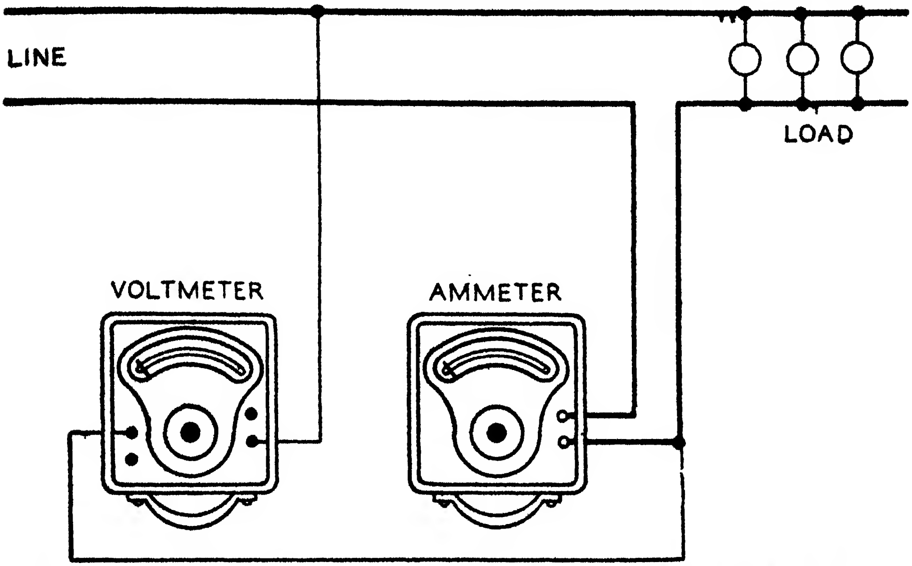


FIG. 4587-10.—Typical connection diagram of voltmeter and ammeter in a single phase circuit. When the instruments are connected as shown, the voltmeter measures *load voltage, not line voltage*. The ammeter measures *load current plus voltmeter current*.

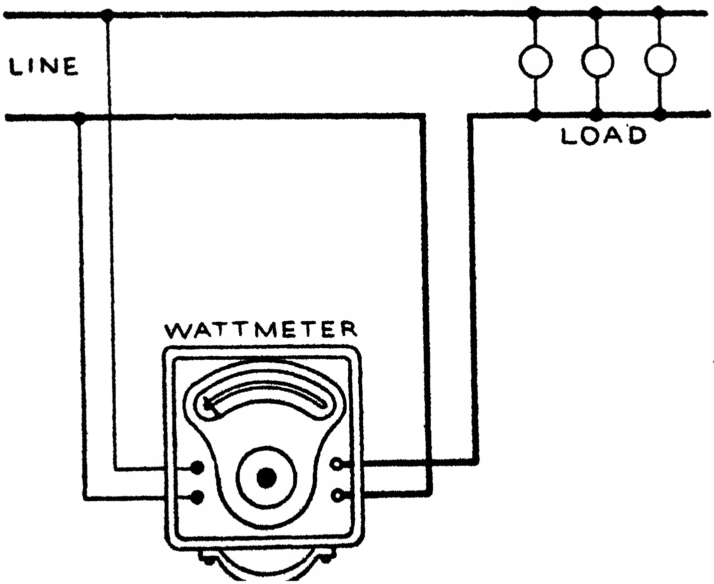


FIG. 4587-11.—Typical wattmeter connection in a single phase circuit. When connected as shown, the instrument is measuring *power load plus losses in its own current coil circuit*. If the instrument reads backwards, reverse the current leads.

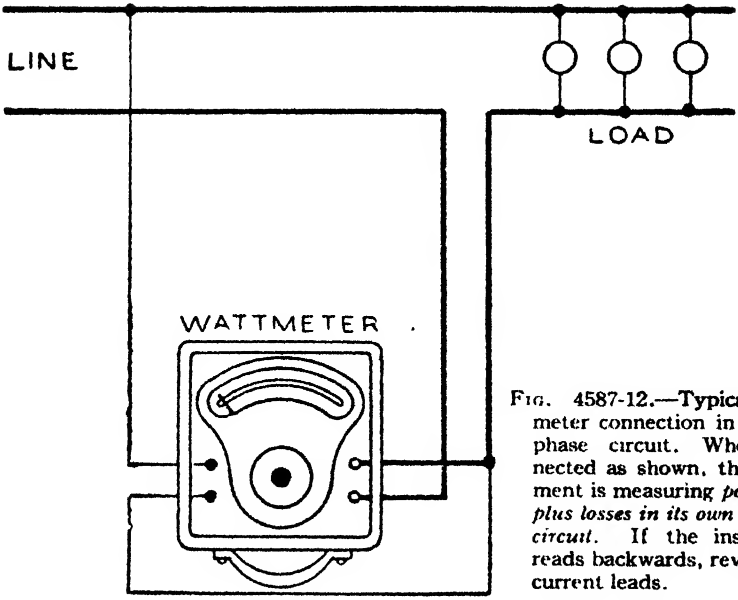


Fig. 4587-12.—Typical wattmeter connection in a single phase circuit. When connected as shown, the instrument is measuring *power load plus losses in its own potential circuit.* If the instrument reads backwards, reverse the current leads.

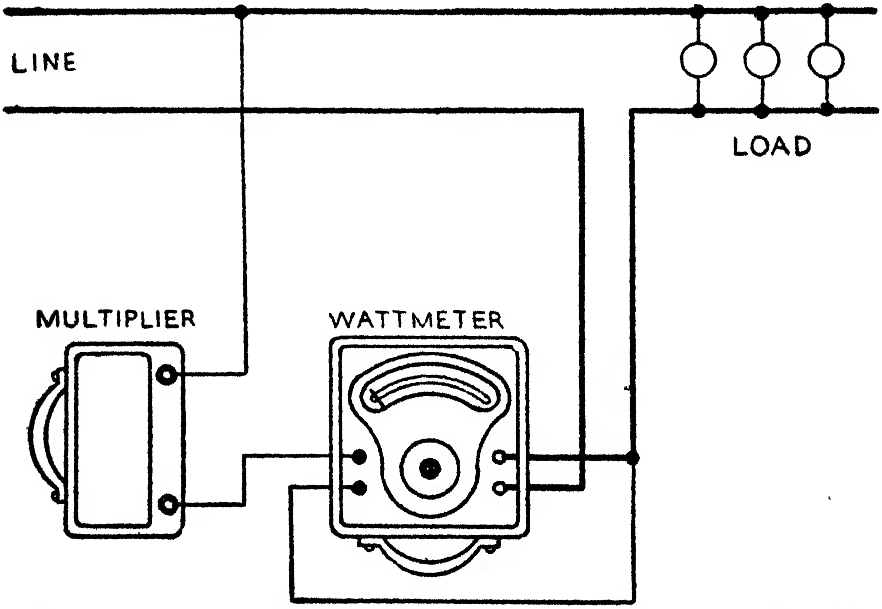


Fig. 3587-13.—Typical wattmeter connection in a single phase circuit, when used with potential multiplier. When connected as shown the instrument is measuring *power load plus losses in its own potential and multiplier circuit.*

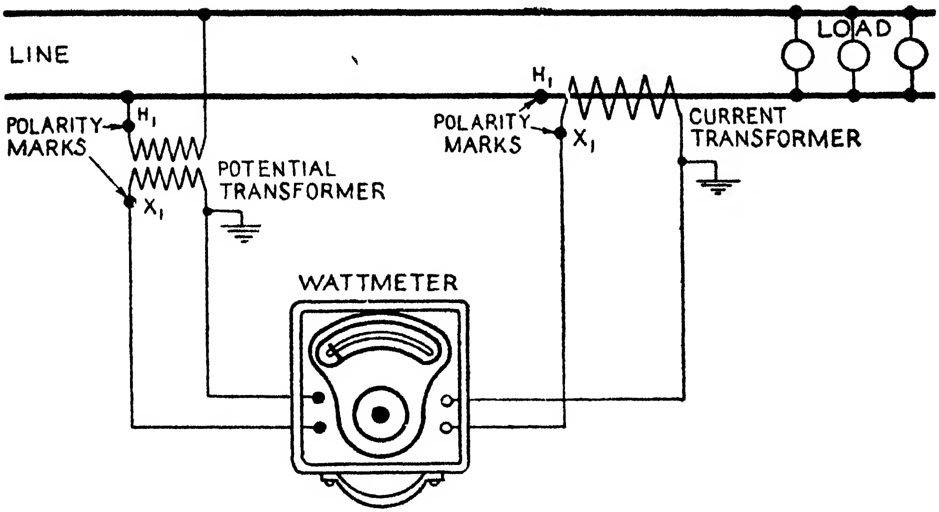


FIG. 4587-14.—Typical wattmeter connections in a single phase circuit, when used with potential and current transformer.

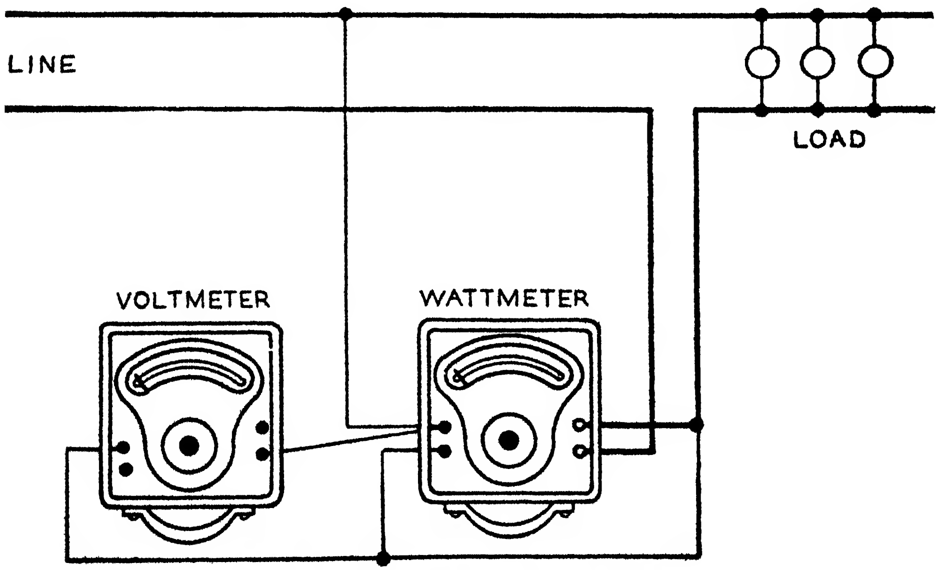


FIG. 4,587-15.—Typical wattmeter and voltmeter connections in a single phase circuit. When connected as shown the wattmeter measures *power load plus losses in the voltmeter and wattmeter potential circuits*.

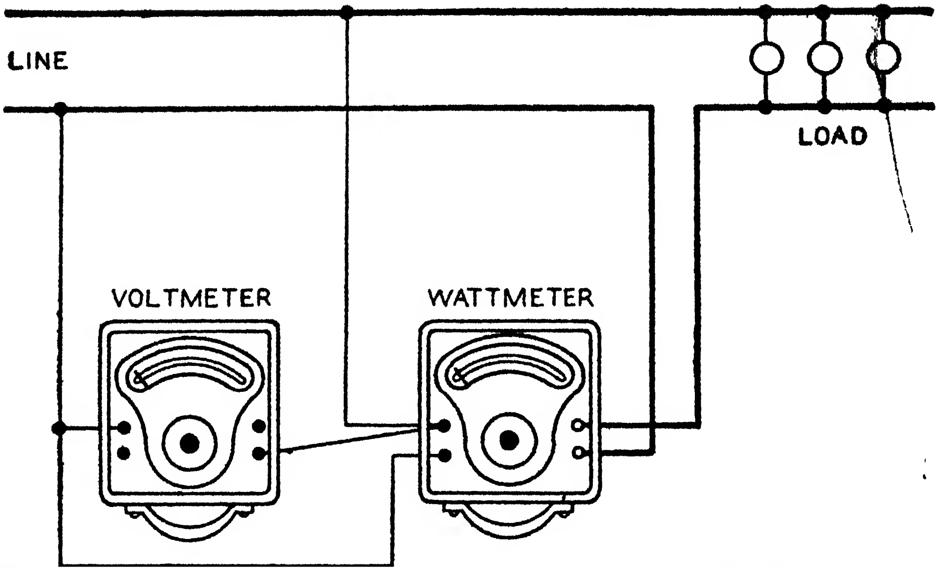


FIG. 4,587-16.—Typical voltmeter and wattmeter connections in a single phase circuit. When connected as shown, the wattmeter measures *power load plus losses in its own current coil circuit.*

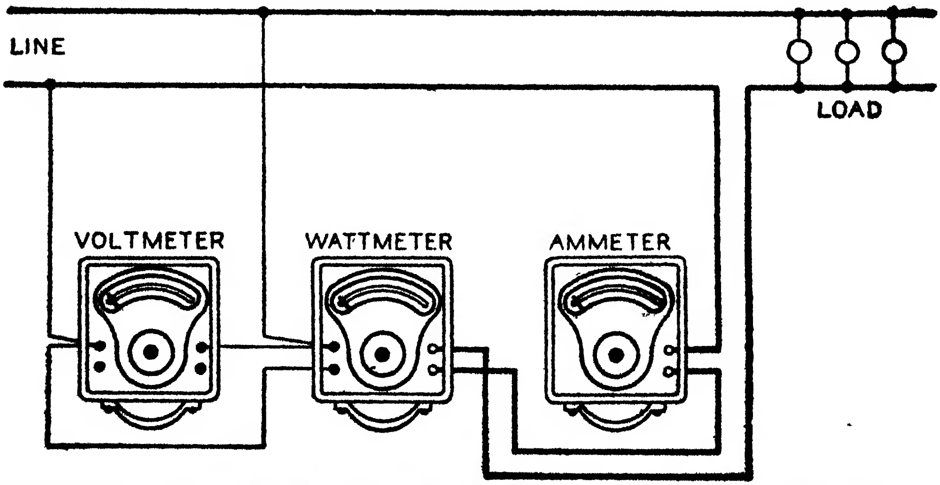


FIG. 4,587-17.—Typical wattmeter, voltmeter and ammeter connections in a single phase circuit. In a meter combination of this type the power factor of the circuit may easily be determined by dividing the wattmeter reading by the product of the voltmeter and ammeter readings. When connected as shown, the wattmeter measures *power load plus losses in the ammeter and wattmeter current-coil circuit.*

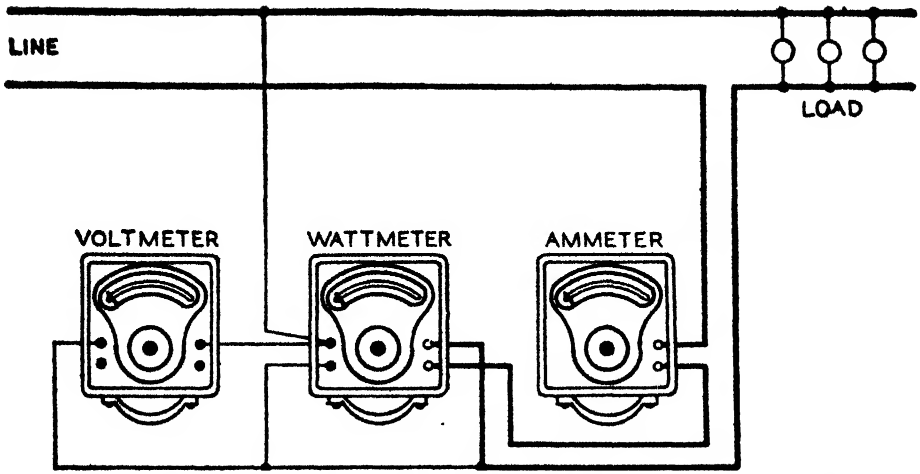


FIG. 4,587-18.—Typical wattmeter, voltmeter and ammeter connections in a single phase circuit. In a meter combination of this type, the power factor of the circuit may easily be determined by dividing the wattmeter reading by the product of the voltmeter and ammeter readings. When connected as shown the wattmeter measures *the sum of the power losses of the load, the potential circuit of the wattmeter and the voltmeter.*

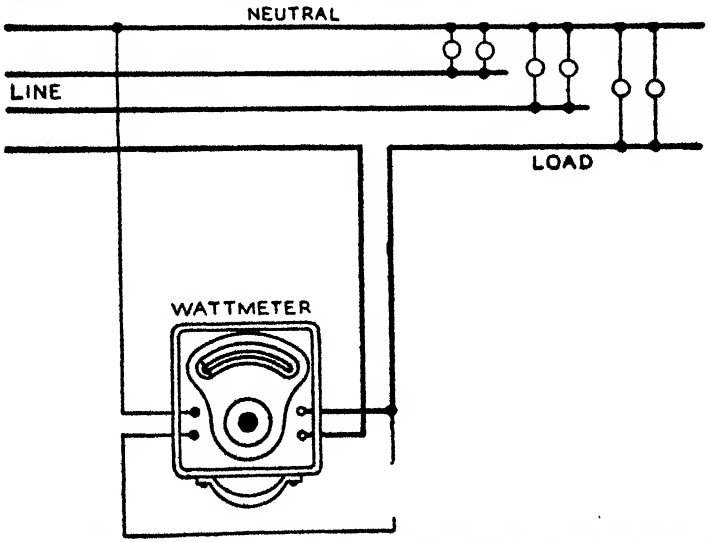


FIG. 4,587-19.—Typical connection diagram of a single wattmeter in a balanced three-phase, four-wire circuit. While only the wattmeter connections are shown, the voltmeter and ammeter may be connected as illustrated in the two preceding diagrams. When connected as shown, the power of the system is three times the indication of the single wattmeter. The wattmeter indicates *its own potential losses plus the power in one phase of the load.*

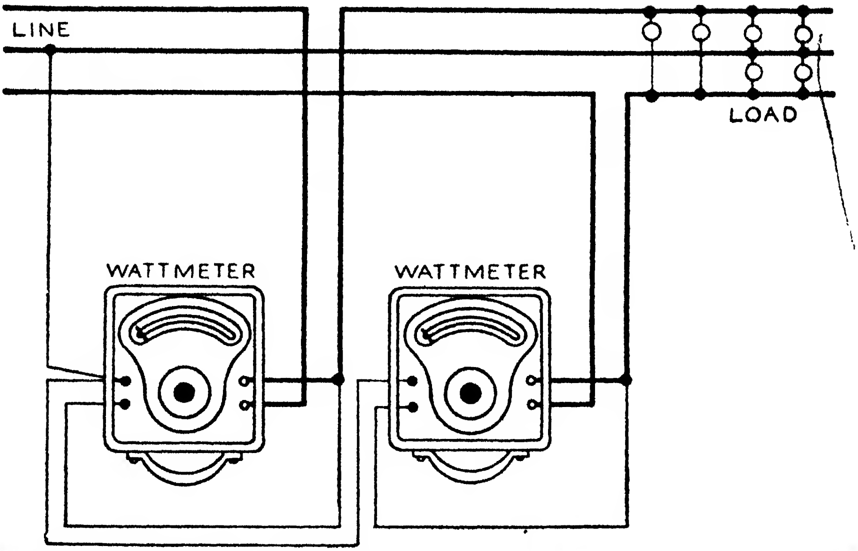


FIG. 4,587-20.—Typical connection diagram of two wattmeters connected for three-phase balanced or unbalanced voltages or load. When connected as shown, the two wattmeters will not indicate alike even if the load is balanced. Thus, for example, above 50% power factor, the three-phase power is the sum of the two readings. Below 50% power factor, it is necessary to reverse the reading of one wattmeter (by reversing its current leads) and then take the difference between the readings of the two instruments.

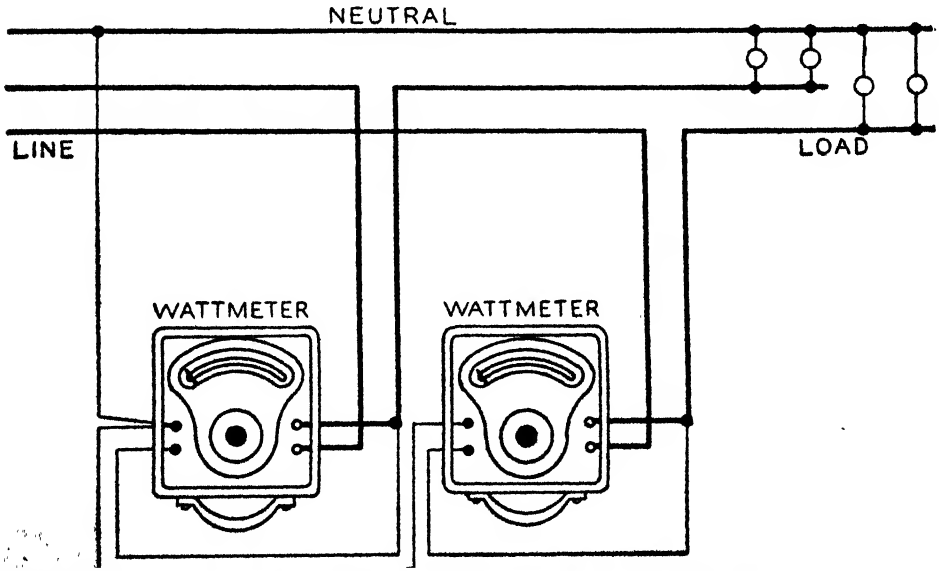


FIG. 4,587-21.—Typical wiring diagram showing two wattmeters connected for two-phase, three-wire balanced or unbalanced load.

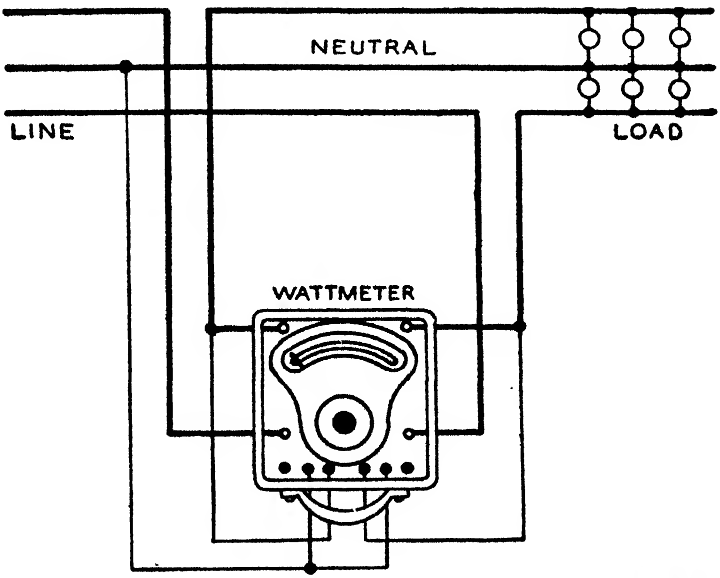


FIG. 4,587-22.—Typical wiring diagram showing connection of a polyphase wattmeter in a two-phase, three-wire circuit, balanced or unbalanced voltage or load.

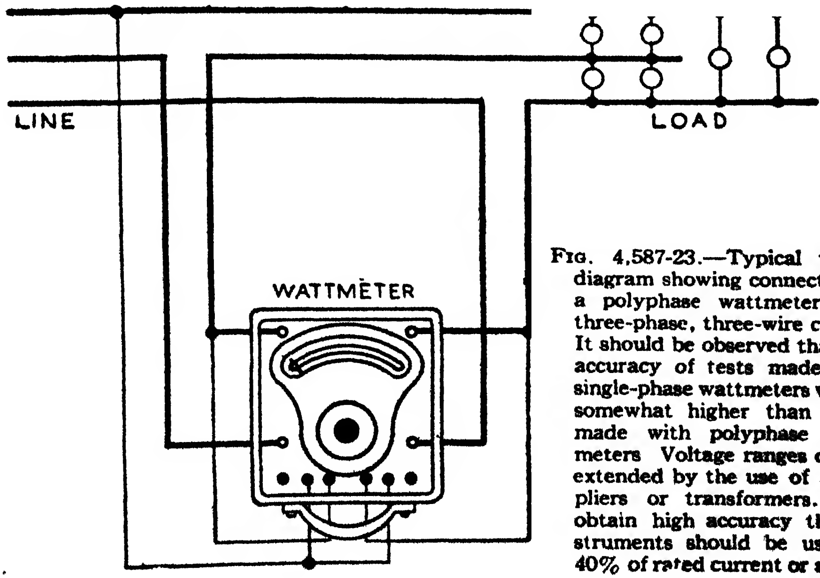


FIG. 4,587-23.—Typical wiring diagram showing connection of a polyphase wattmeter in a three-phase, three-wire circuit. It should be observed that the accuracy of tests made with single-phase wattmeters will be somewhat higher than those made with polyphase wattmeters Voltage ranges can be extended by the use of multipliers or transformers. To obtain high accuracy the instruments should be used at 40% of rated current or above.

Power-Factor Meter Connections.—The power factor of an alternating current circuit is measured by a *power-factor meter*.

By definition, the power factor of a circuit is the ratio between the *effective* power and the *apparent* power. It has previously been shown how the effective power in a three-phase circuit may be measured by means of two wattmeters.

If, in addition to the two wattmeters shown in fig. 4,587-20, a voltmeter and an ammeter be connected in the circuit in the conventional manner, the apparent power is found by multiplying the product of the voltmeter and ammeter indications by 1.73. If the system be only slightly out of balance, the average readings of an ammeter placed in each lead successively may be taken as the current, and the average voltage between the leads as the potential.

Since the *active* or *effective* power may be obtained from the wattmeter readings and the *apparent* power from the readings of the volt and ammeters, the power factor of the load may be obtained from the equation:

$$\text{Power-factor} = \frac{\text{Effective power}}{\text{Apparent power}} \text{ or}$$

$$\text{Power factor} = \frac{\text{Sum of wattmeter readings}}{1.73 \times \text{average line volts} \times \text{average line current}}$$

In order to obviate the necessity of using four meters with the accompanying high cost and complications, one single instrument known as the *power-factor* meter may be used to obtain the power factor of the load.

This type of meter by its design contains the necessary elements for measuring the power factor by a direct indication.

Typical power factor meter connections in various power systems are shown in figs. 4,587-24 to 4,587-26.

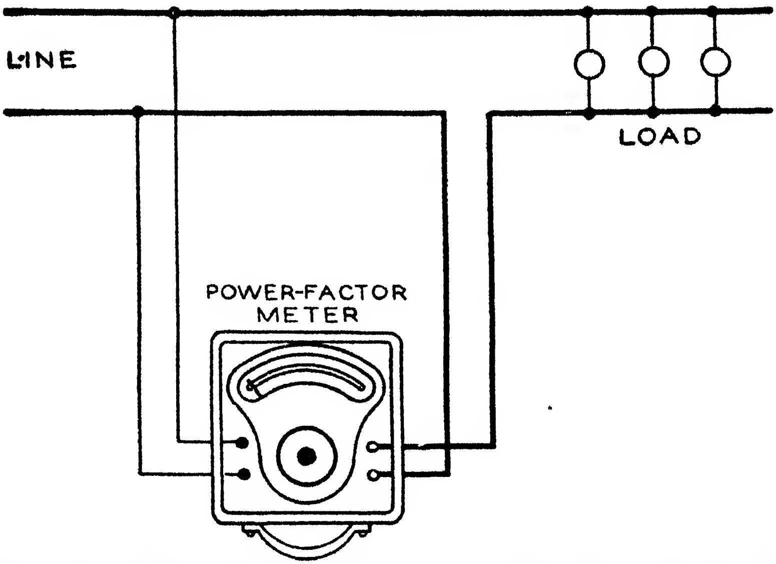


Fig. 4,587-24.—Typical power factor meter connection when used on a single phase circuit. Single-phase power factor meters should be used only at the calibrated frequency.

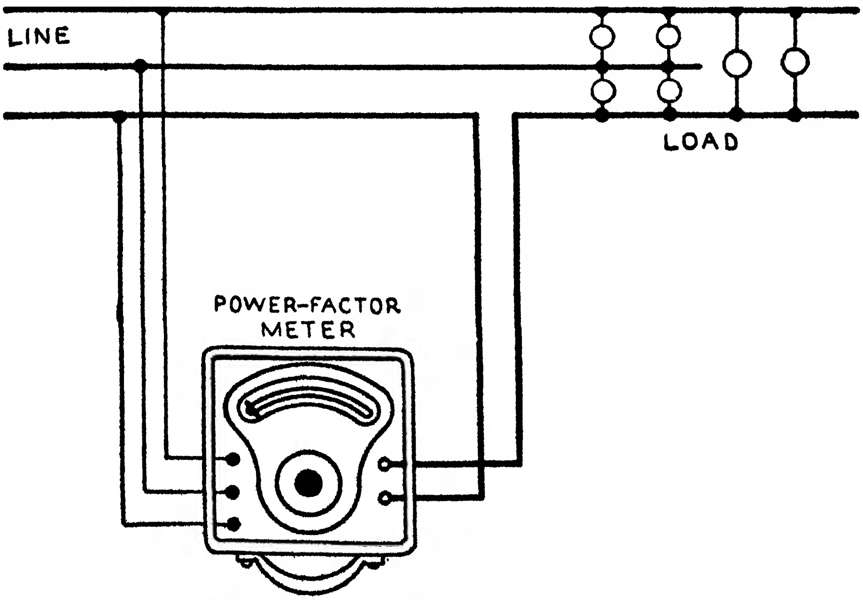


Fig. 4,587-25.—Typical power factor meter connection when used on a three-phase, three-wire circuit.

TEST QUESTIONS

1. *Name a few meters of a miscellaneous nature.*
2. *What is the construction of a power factor meter?*
3. *Name two types of power factor meters.*
4. *How does a watt meter type power factor meter work?*
5. *Describe the disc or rotating field type of power factor meter.*
6. *What is the ordinary range of power factor measurements?*
7. *What is a phase indicator intended for?*
8. *Give one method of checking the connections of a 3 wire, 3 phase power factor indicator.*
9. *What is the special use of the phase indicator?*
10. *State briefly the principle on which phase indicators operate.*
11. *What is a synchronism indicator?*
12. *Name three types of synchronism indicators.*
13. *Describe the lamp or volt meter type of synchronism indicator.*
14. *Describe the rotating field type of synchronism indicator.*
15. *What is the principle of operation of the rotating field type synchronism indicator?*
16. *What is the object of a frequency meter?*
17. *Name three types of frequency meters.*
18. *Describe the several types of frequency indicators.*
19. *Explain how to read a Frahm frequency meter.*

CHAPTER 87

Measurements of Power

There are two principal methods whereby power may be measured in a three-phase system, namely:

1. The *three-wattmeter* method, and
2. *The two-wattmeter* method

With reference to fig. 1 employing three wattmeters, the total power delivered is equal to the sum of the individual meter readings, or

$$P = W_1 + W_2 + W_3, \text{ watts} \tag{1}$$

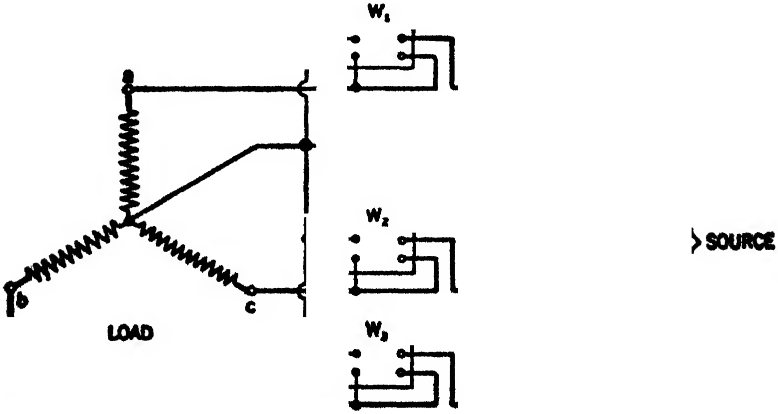


Fig. 1.—Measurement of three-phase power by employment of three wattmeters.

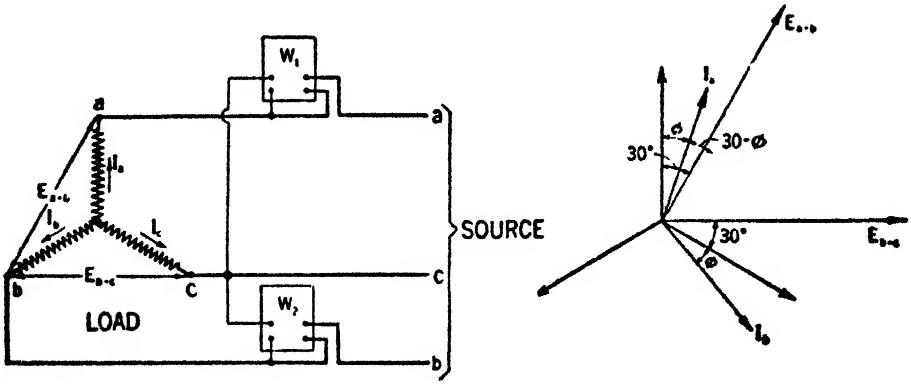
If the star center of a load is not available as is often the case, or if the load be connected in delta, correct wattmeter readings may be obtained by connecting the three ends of voltage coils together

If the load be balanced, the total power may be determined from the readings of a single wattmeter since the power is

$$P = 3W, \text{ watts}$$

or three times as great as that indicated by one wattmeter.

In the two-wattmeter method the wattmeters will measure the total amount of power if connected as shown in fig. 2. The corresponding vector relations are shown in fig. 3.



FIGS. 2 and 3.—Measurement of three-phase power by using two wattmeters. The number of wattmeters(Wm) required if there be N phases are $W_m = N-1$, that is, the number of meters are one less than the number of phases to be measured.

With reference to fig. 2, W_1 is connected to measure current I_a and the voltage E_{a-b}. The angle between the voltage and current is $(30-\phi)$ The readings of meter W_1 is

$$W_1 = EI\cos(30-\phi) \text{ watts} \tag{2}$$

Similarly the reading of meter W_2 is

$$W_2 = EI\cos(30+\phi) \text{ watts} \tag{3}$$

The three phase power is

$$P = W_1 + W_2 = EI\cos(30-\phi) + EI\cos(30+\phi)$$

Substituting the equation for the cosine of the sum and difference of two angles (from trigonometry) we obtain

$$P = EI(\cos 30 \cos\phi + \sin 30 \sin\phi) +$$

$$EI\ (\cos 30 \cos\phi - \sin 30 \sin\phi)$$

and

$$P = EI\left(\frac{\sqrt{3}}{2}\cos\phi + \frac{1}{2}\sin\phi + \frac{\sqrt{3}}{2}\cos\phi - \frac{1}{2}\sin\phi\right)$$

from which

$$P = \sqrt{3}EI\cos\phi, \text{ watts} \tag{4}$$

This is the general formula for power in a three-phase circuit as previously developed.

When the phase angle ϕ is less than 60° (that is, the power factor is greater than 0.5) both wattmeters will read on scale and the total power is

$$P = W_1 + W_2, \text{ watts} \tag{5}$$

When the phase angle ϕ is equal to 60°, wattmeter W_2 will read zero since I_b will lag the voltage by 90°, and W_1 reads the total power of the system. In this case the power factor equals 0.5.

Finally when the phase angle ϕ is greater than 60°, that is, the power factor is less than 0.5, W_2 reads negative and the connection to the current coil must be reversed, and since its resultant reading is negative, the total power is

$$P = W_1 - W_2, \text{ watts} \tag{6}$$

If it be desired to obtain a relation between the phase angl and the two meter readings, we may write

$$\frac{W_1-W_2}{W_1+W_2}=\frac{EI\cos(30-\phi)-EI\cos(30+\phi)}{EI\cos(30-\phi)+EI\cos(30+\phi)}$$

and

$$\frac{W_1-W_2}{W_1+W_2}=\frac{2\sin 30\sin\phi}{2\cos 30\cos\phi}=tg\,30\,tg\,\phi=\frac{tg\phi}{\sqrt{3}}$$

or

$$tg\phi=\sqrt{3}\frac{W_1-W_2}{W_1+W_2} \tag{7}$$

In the above formula ϕ is the angle of lag, or lead of the current and W_1 and W_2 the readings of the wattmeters.

A table giving the value of the power factor ($\cos\phi$) for W_2/W_1 is inserted on page 2,687 and may be used for either positive or negative value of the quotient.

As a suitable exercise in the treatment of the above formulas the following examples are given:

Example.—*The power supplied to a three-phase induction motor is measured by two wattmeters which read* 9 *and* 5 *kilowatts respectively. If the line potential be* 440 *volts, how much current does the motor draw from the line?*

Solution.—The angle of lag of the current is obtained by inserting the above values in formula for $tg\,\phi$ or

$$tg\phi=\sqrt{3}\frac{W_1-W_2}{W_1+W_2}=\sqrt{3}\frac{9-5}{9+5}=0.495$$

and $\phi=26.3°$ and $\cos\phi=0.9$ (approximately)

Since in this instance the phase angle is less than 60° (i.e. the power factor is greater than 0.5) the total power is obtained by an addition of the two meter readings or

$$P=W_1+W_2=9+5=14 \text{ kilowatts}$$

We may write

$$14{,}000=\sqrt{3}\times440\times I\times0.9$$

from which

$$\frac{14{,}000}{\sqrt{3}\times440\times0.9}=20.4 \text{ amperes.} \quad \textit{Ans.}$$

Example.—*Two wattmeters are used to measure the power in a balanced three-phase circuit. The line voltage is 240 volts, the line current is 50 amperes and the phase power factor is 80%. What are the readings of the two wattmeters?*

Solution.—

The reading of wattmeter

$$W_1=EI\cos(30-\phi)=240\times50\times\cos(30°-36.9°)$$

$$=-240\times50\times0.9928=-11.9136 \text{ kw. (Backward)}$$

Reading of wattmeter

$$W_2=EI\cos(30+\phi)=240\times50\cos(30°+36.9°)$$

$$=240\times50\times0.3923=4.7076 \text{ kw. (Correct)}$$

The total power

$$=W_1+W_2=11.9136+4.7076=16.6212 \text{ kw.} \quad \textit{Ans.}$$

The same total power will be obtained by the use of equation

$$P=EI\cos\phi\sqrt{3}=240\times 50\times 0.8\sqrt{3}=16.6212 \text{ kw. (check)}$$

Example.—*Two wattmeters are connected into a balanced three-phase system to measure the power. What is the power factor if*

(*a*) *Two meters read the same*

(*b*) *One meter reads zero*

(*c*) *One meter reads twice as much as the other*

Solution.—There are several methods whereby a solution to the above problem may be obtained.

With reference to our formula we obtain in the first instance

(a) $$tg\phi=\sqrt{3}\frac{W_1-W_2}{W_1+W_2}=\frac{0}{2W_1}=0 \text{ and } \phi=0$$

that is $\cos\phi=1$ or unity power factor. *Ans.*

(b) $$tg\phi=\sqrt{3}\frac{W_1}{W_1}=\sqrt{3}$$

which corresponds to an angle of 60°. Hence $\cos\phi=0.5$. *Ans.*

(c) $$tg\phi=\sqrt{3}\frac{2W_2-W_2}{3W_2}=\frac{\sqrt{3}}{3} \text{ and } \phi=30°$$

from which $\cos\phi=0.866$. *Ans.*

TABLE
VALUE OF COS θ (POWER FACTOR) FOR $\frac{W_2}{W_1}$

$\frac{W_2}{W_1}$ Positive

$\frac{W_2}{W_1}$	Cos θ	$\frac{W_2}{W_1}$	Cos θ	$\frac{W_2}{W_1}$	Cos θ	$\frac{W_2}{W_1}$	Cos θ	$\frac{W_2}{W_1}$	Cos θ
0.847	0.99	0.554	0.89	0.381	0.79	0.246	0.69	0.117	0.59
0.790	0.98	0.525	0.88	0.367	0.78	0.233	0.68	0.104	0.58
0.747	0.97	0.507	0.87	0.353	0.77	0.220	0.67	0.092	0.57
0.712	0.96	0.490	0.86	0.339	0.76	0.207	0.66	0.079	0.56
0.681	0.95	0.473	0.85	0.325	0.75	0.193	0.65	0.066	0.55
0.654	0.94	0.457	0.84	0.312	0.74	0.181	0.64	0.053	0.54
0.629	0.93	0.441	0.83	0.298	0.73	0.168	0.63	0.039	0.53
0.605	0.92	0.425	0.82	0.285	0.72	0.156	0.62	0.026	0.52
0.583	0.91	0.410	0.81	0.272	0.71	0.143	0.61	0.013	0.51
0.563	0.90	0.396	0.80	0.259	0.70	0.130	0.60	0.000	0.50

$\frac{W_2}{W_1}$ Negative

$\frac{W_2}{W_1}$	Cos θ	$\frac{W_2}{W_1}$	Cos θ	$\frac{W_2}{W_1}$	Cos θ	$\frac{W_2}{W_1}$	Cos θ	$\frac{W_2}{W_1}$	Cos θ
0.013	0.49	0.154	0.39	0.312	0.29	0.498	0.19	0.729	0.09
0.027	0.48	0.169	0.38	0.329	0.28	0.519	0.18	0.756	0.08
0.041	0.47	0.183	0.37	0.346	0.27	0.540	0.17	0.784	0.07
0.054	0.46	0.199	0.36	0.364	0.26	0.562	0.16	0.811	0.06
0.068	0.45	0.214	0.35	0.382	0.25	0.584	0.15	0.840	0.05
0.082	0.44	0.230	0.34	0.400	0.24	0.606	0.14	0.870	0.04
0.096	0.43	0.246	0.33	0.419	0.23	0.630	0.13	0.902	0.03
0.110	0.42	0.262	0.32	0.438	0.22	0.654	0.12	0.933	0.02
0.125	0.41	0.279	0.31	0.458	0.21	0.678	0.11	0.967	0.01
0.139	0.40	0.295	0.30	0.478	0.20	0.703	0.10	1.000	0.00

FIG. 4.—Table giving ratio $\frac{W_2}{W_1}$ of wattmeter readings and corresponding power factor. Assume for example that two wattmeters connected as shown in fig. 2, are giving a positive reading of $W_1 = 4{,}000$ and $W_2 = 1{,}892$. The ratio $\frac{W_2}{W_1} = \frac{1{,}892}{4{,}000} = 0.473$. The corresponding power factor *(continued on next page)*

Example.—*In a balanced three phase 208 volt circuit the line current is 100 amperes. The power is measured by the two watt meter method and one watt meter reads 18 k.w. and the other zero. What is the power factor of the load? If the power factor were unity and the line current the same what would each watt-meter read?*

Solution.—The expression for power is

$$P = EI\cos\phi\sqrt{3}$$

since one watt-meter reads zero

$$P = 18{,}000 = 208 \times 100 \times \cos\phi \times \sqrt{3}$$

and

$$\cos\phi = \frac{18{,}000}{208 \times 100 \times \sqrt{3}} = 0.5. \quad \textit{Ans.}$$

With the power factor unity and the same line current, we obtain according to equation (7)

$$tg\,\phi = \sqrt{3}\frac{W_1 - W_2}{W_1 + W_2} = 0 \text{ or } W_1 = W_2$$

Also

$$W_1 + W_2 = 208 \times 100 \times \sqrt{3} = 36 \text{ k.w.}$$

That is, each watt-meter reads 36/2 or 18 Kw. ***Ans.***

for this ratio from table = 0.85 or 85%. As a check we may insert our values in equation (7), or

$$tg\phi = \sqrt{3}\,\frac{W_1 - W_2}{W_1 + W_2} = \sqrt{3}\,\frac{4{,}000 - 1{,}892}{4{,}000 + 1{,}892} = \sqrt{3}\,\frac{2{,}108}{5{,}892} = 0.6196$$

and $\phi = 31.8°$. The power factor corresponding to this angle is 0.8499 or 85%.

CHAPTER 88

Switchboards

In all buildings where electricity is generated, converted, transformed, or utilized to any great extent, the control of the equipment is arranged, in so far as practicable, for the most convenient attention and operation.

The control and indicating devices are mounted on *some form of structure at a particular point, and the whole assemblage is known as a* **switchboard.**

The design of switchboards is dependent upon the kind and capacity of apparatus to be controlled, the types of devices to be used, the buildings in which the switchboards are to be installed, and upon future additions and alignments with existing installations.

Switchboards are usually built of

1. Slate.
2. Ebony asbestos.
3. Marble.

and they may be classified as

1. Live front boards (vertical).
2. Live front boards (bench).
3. Dead front boards.

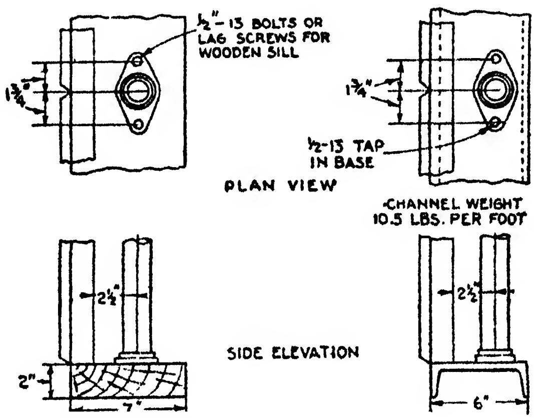
   a. Safety enclosed, vertical.

b. Safety enclosed, sectional.

c. Safety enclosed, truck.

Special designs are also built when necessary to meet unusual requirements.

Foundation.—The switchboard should stand on a level foundation sill made of hard wood or channel iron, as shown in figs. 4,626 to 4,629. The sill must be rigid and heavy enough



FIGS. 4,626 to 4,629.—Standard sill and switchboard sub-base arrangements.

so that the panels will not be thrown out of line by settling. Standard 6 in. channels are best, although hard wood sills 7×2 ins. may be used and are recommended where insulated frame work is required.

The sill should be securely anchored. Drill the channel sill for anchor bolts to suit floor construction. A method of *grouting* the channels is shown in fig. 4,632.

A small brick pier should be built at each end, and sand or plaster piled along the sides of the channel to prevent the cement leaking out. The mixture should be about one part sand to one part cement and should flow freely. By pouring it into the piers until the level rises above the top of the channel, a head will be produced which will force the cement underneath the channel.

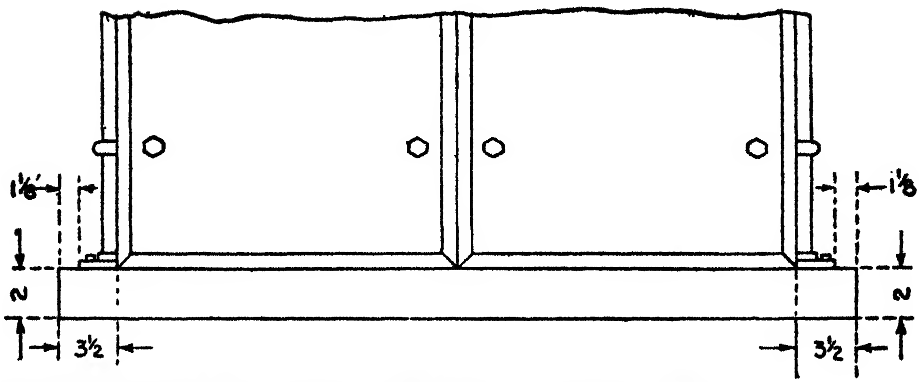
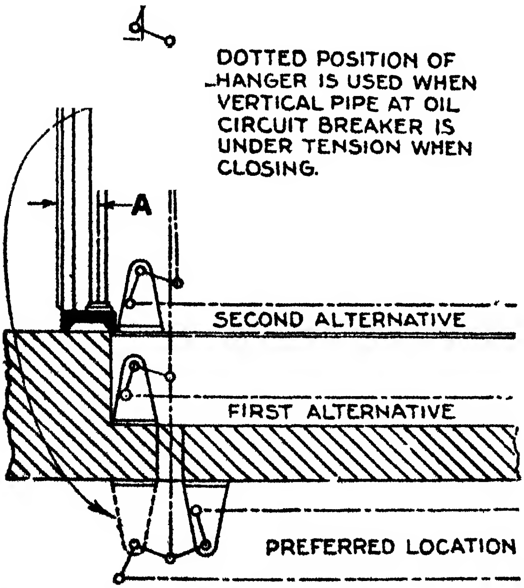


Fig. 4,630.—Arrangement of channel base when end grill is not used.



The tapped holes in the sill should be plugged with wood before pouring the cement, or the bolts for the floor flanges should be screwed into the channel temporarily to the maximum depth, in order to prevent the cement filling them and making it difficult to fasten the flanges to the channel. The grouting should be allowed to set for twenty-four hours before mounting the panels on the sill.

It cannot be too strongly emphasized that the leveling, anchoring and grouting of the sill are important operations and the final appearance of the switchboard is dependent largely on the care and patience exercised.

Fig. 4,631.—Arrangement of channel base, panel sub-base, and panel supports, showing preferred and alternative locations of lower vertical hanger for pipe mechanism, for remote controlled oil circuit breakers.

The method of anchoring panel braces is dependent on construction of the wall. Heavy panel equipment requires solid fastenings. Expansion bolts, through bolts, or an angle iron bolted along the wall may be used.

Erection.—The panel frame consists of either 1¼ in. upright pipe supports, angle irons, or, in cases where the equipment is

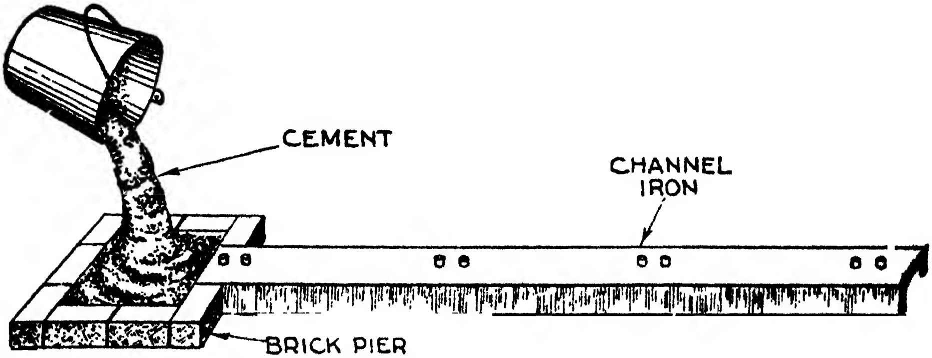


FIG. 4,632.—Method of grouting channel in sill.

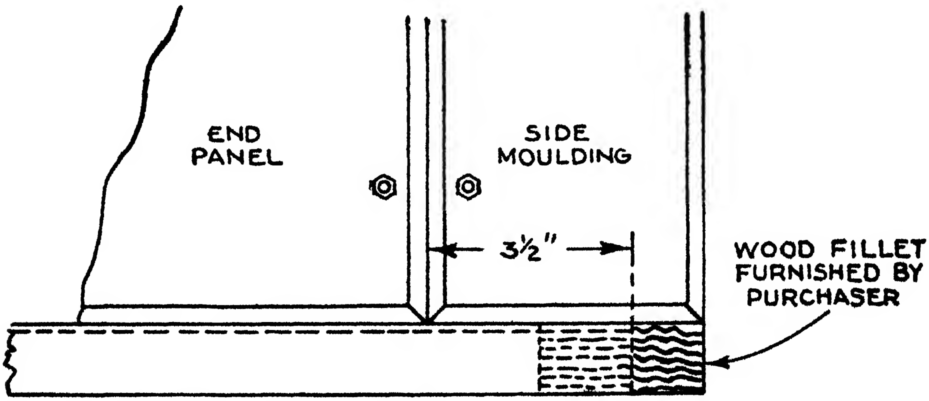


FIG. 4,633.—Arrangement of channel base when end grill is used.

exceptionally heavy, channel irons. A standard method of bracing switchboard panel supports is shown in fig. 4,634. Regardless of frame construction and method of shipping panels, whether assembled or dismantled, the middle panel should be erected first, plumbed and braced securely.

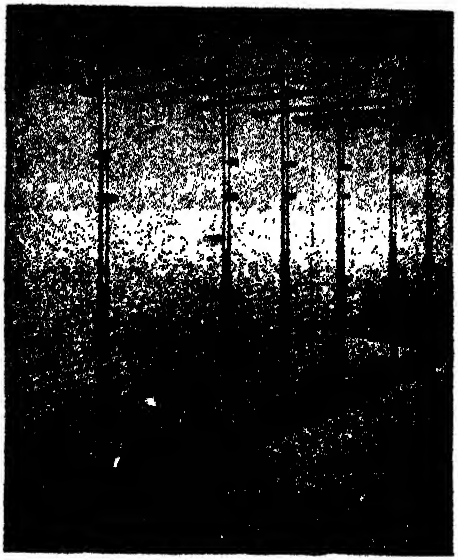
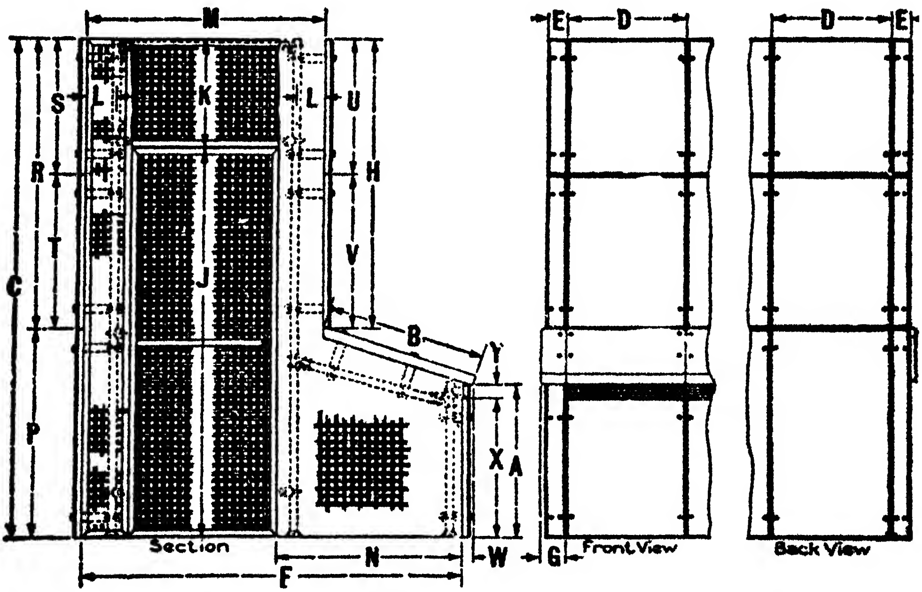


Fig. 4,634.—Pipe frame structure for a 90 inch board. The best results in a finished switchboard are obtained by first setting the frame structure accurately. Plumb and align it carefully before bolting it to the sill and wall

Fig. 4,635.—Erecting a switchboard of three section panels which have been shipped as individual sections. Leatheroid washers are placed between the panels and pipe fittings to align the front surface of the board. Each row of sections is leveled and aligned completely before the panel bolts are tightened.

stiffness and weight and their ease of assembling and adjustment. Note the suggested method in figs. 4,647 and 4,648, of bracing a switchboard when the board extends across a window or other opening in the wall.

All such structures should be well braced together to avoid any flexibility that might tend to affect operation of oil circuit breakers, or transmit jars from them to the panels. The threadless clamp fittings offer in this respect the best facilities for perfect adjustment. In heavy capacity installations, avoid carefully any complete magnetic circuits around a conductor carrying a great amount of current.



FIGS. 4,638 to 4,640.—Typical bench board construction. Fig. 4,638 cross section, fig. 4,639 front view; fig. 4,640, back view.

Make sure of an effective ground and see that paint on pipes or fittings does not prevent a good connection. There should never be more than three clamped or screwed joints in series for each ground connection.

Pipe caps should be slipped on the exposed ends of all pipes to improve the general appearance of the installation. All metal work should be painted from time to time for protection and appearance.

Classes of A.C. Switchboards.—Depending upon the mounting and method of operation of the apparatus *a.c.* switchboards may be classified as

1. Direct control boards. 2. Remote control boards.

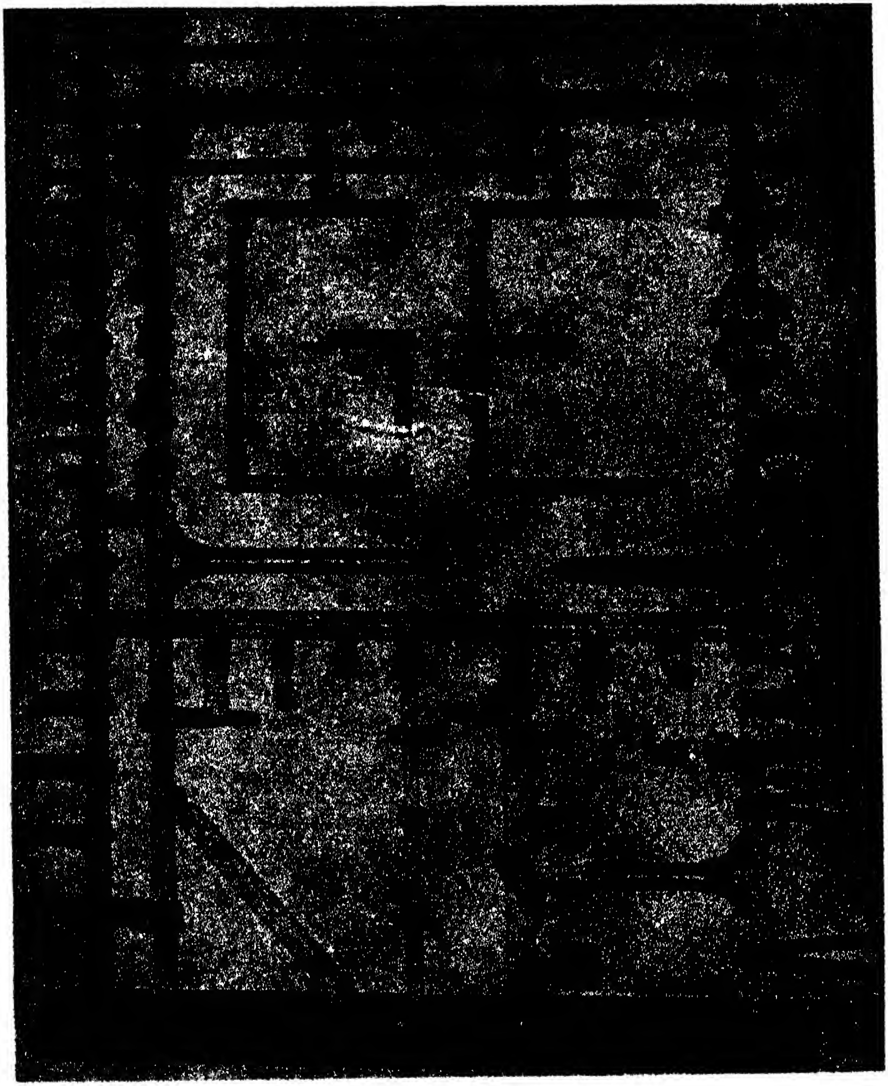
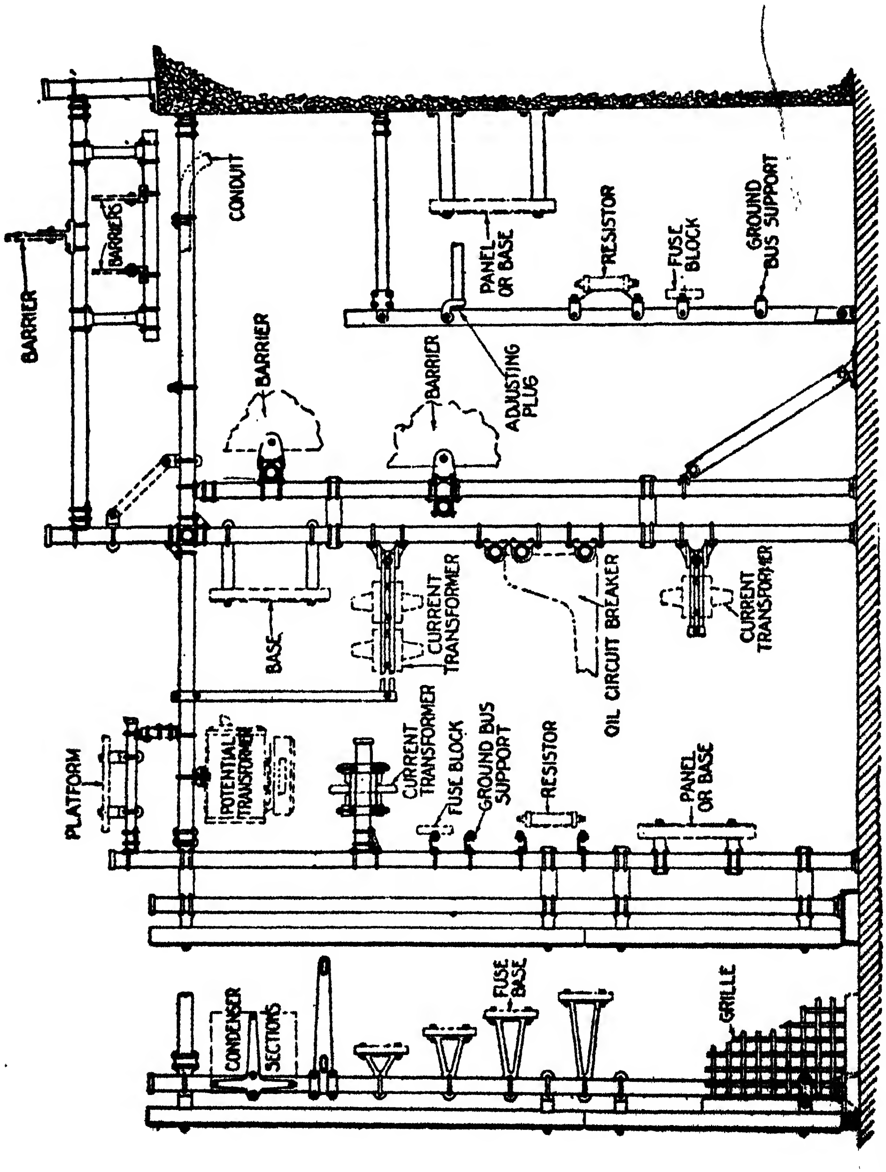
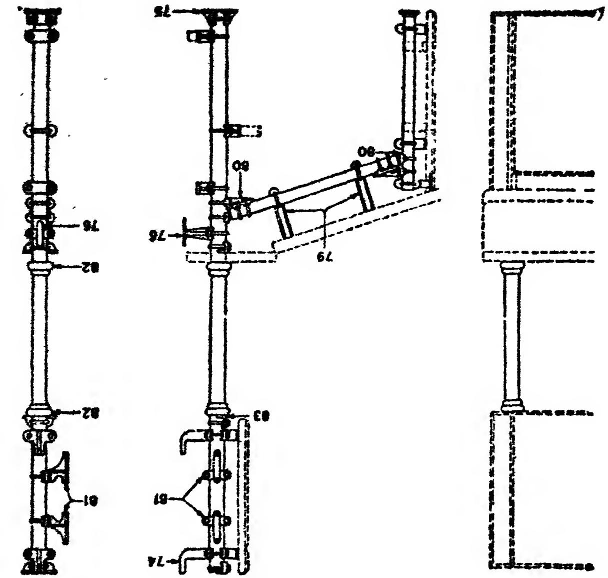


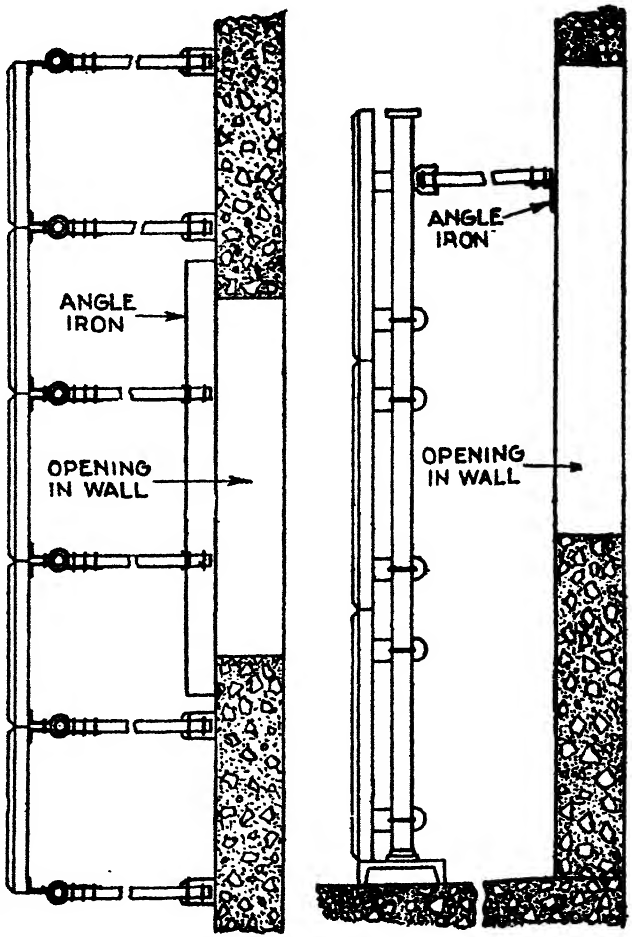
FIG. 4,641.—Standard switchboard pipe fittings.



FIGS. 4,642 and 4,643.—Application of switchboard pipe fittings.



FIGS. 4,644 to 4,646.—Application of benchboard fittings.



FIGS. 4,647 and 4,648.—Method of bracing a switchboard when it extends across a window or other opening in the wall. (An angle iron is bolted across the opening and the rods are fastened to it.)

Direct Control Switchboards.—This type of board has all the apparatus mounted, either directly or partly upon the panels and the remainder on the panel supporting frame work. A direct control board is shown in fig. 4,649.

Manual Remote Control Switchboards.—On boards of this type only the lighter pieces of apparatus are mounted. The main circuit breakers and their associated apparatus are supported upon suitable frame work at a reasonable distance from the panel board.

The oil circuit breakers or other switching devices are operated by means of suitable operating rods and links attached to a handle or handles on the front of the panels. Fig. 4,650 shows a manual remote control board.

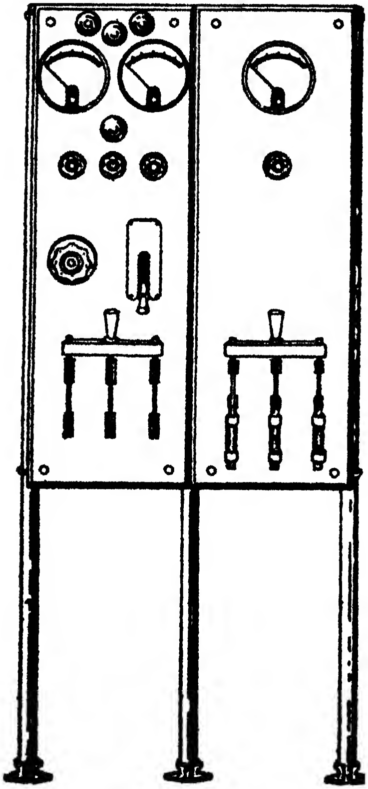


FIG. 4,649.—**Westinghouse 600 volt, direct control switchboard for the control of 1 to 3 alternators. This board is designed for the control of from 1 to 3 alternators in small industrial plants or isolated generating stations operating at 600 volts or less. The panels are approximately 48 inches high, mounted on tubular pipe frame work, with the top of the panel approximately 76 inches from the floor line. Sometimes the panel has a lower section, other times not, depending upon the amount of apparatus to be mounted upon the respective panels. Usually, the capacity per panel is limited to about 600 amperes with not more than 5 panels aggregating 1,800 amperes total. In this type of board, the instrument and control equipment is reduced to a minimum and only those meters that are absolutely necessary for the proper operation are provided.**

The electrically controlled switchboard usually takes one of three general forms, namely:

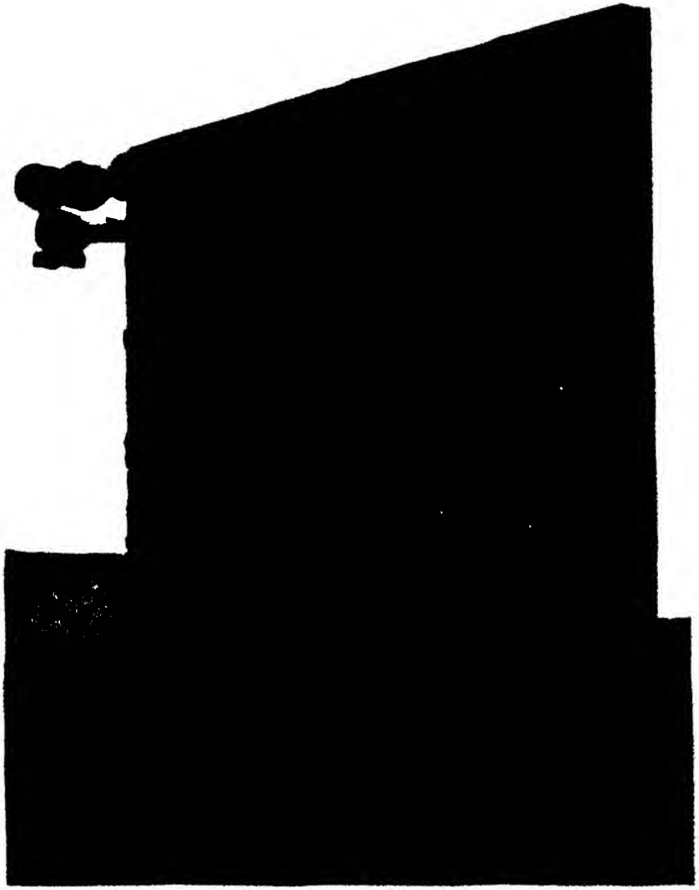
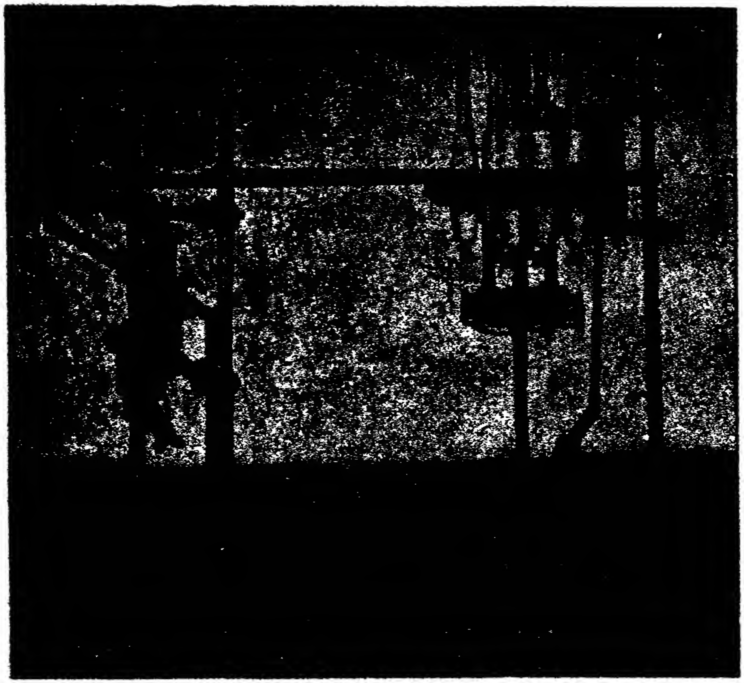


Fig. 4,650.—Manual remote control switchboard. Boards of this type often have the general meter equipment as the direct control board. Since they usually have control over larger amounts of power, the metering equipment is apt to be somewhat more elaborate and the relay equipment is more complicated. They are applicable where the simplicity of connections or accessibility desired cannot be obtained with the panel mounted apparatus or where station capacity or voltage is so high as to make it desirable to mount the oil circuit breakers apart from the panel and where the station arrangement permits the use of manually operated, remote controlled oil circuit breakers. The mechanical limitations of the manual remote control switchboard are: 1. Distance between location of the switchboard panel and its correlated oil switching devices. 2. The effort required to operate the switching devices through the system of bell cranks and connecting rods. This usually limits this type of board to stations of 25,000 *kw*. capacity.



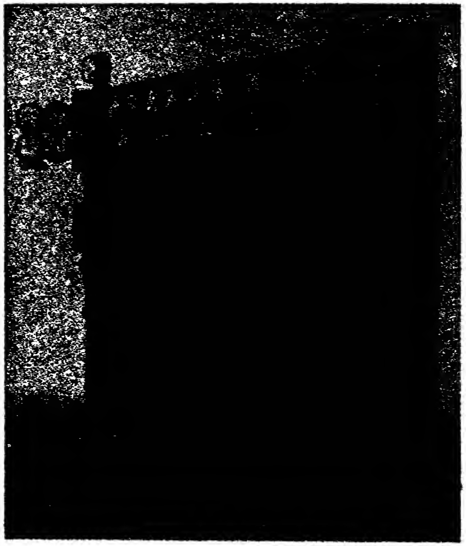


FIG. 4,651.—Mechanism used in remote mechanically controlled switchboard.

FIG. 4,652.—Westinghouse electrically operated remote control switchboard. Capacity, any amount of power up to the maximum concentration. Obviously, all large stations involving the use of high rupturing capacity oil breakers naturally use the electrical remote control switchboard. In some power house layouts, there may be a combination of either two or three of these classes of switchboard. The main circuits being controlled from the electrical remote control board and the auxiliary circuit handled either from a direct control board or a manual, remote control board. Present day designs of large power stations use the electrically operated boards for auxiliary circuits as well as the main circuits.

1. The panel board.
2. The combination control desk and elevated instrument board
3. The combination bench section and instrument panel board.

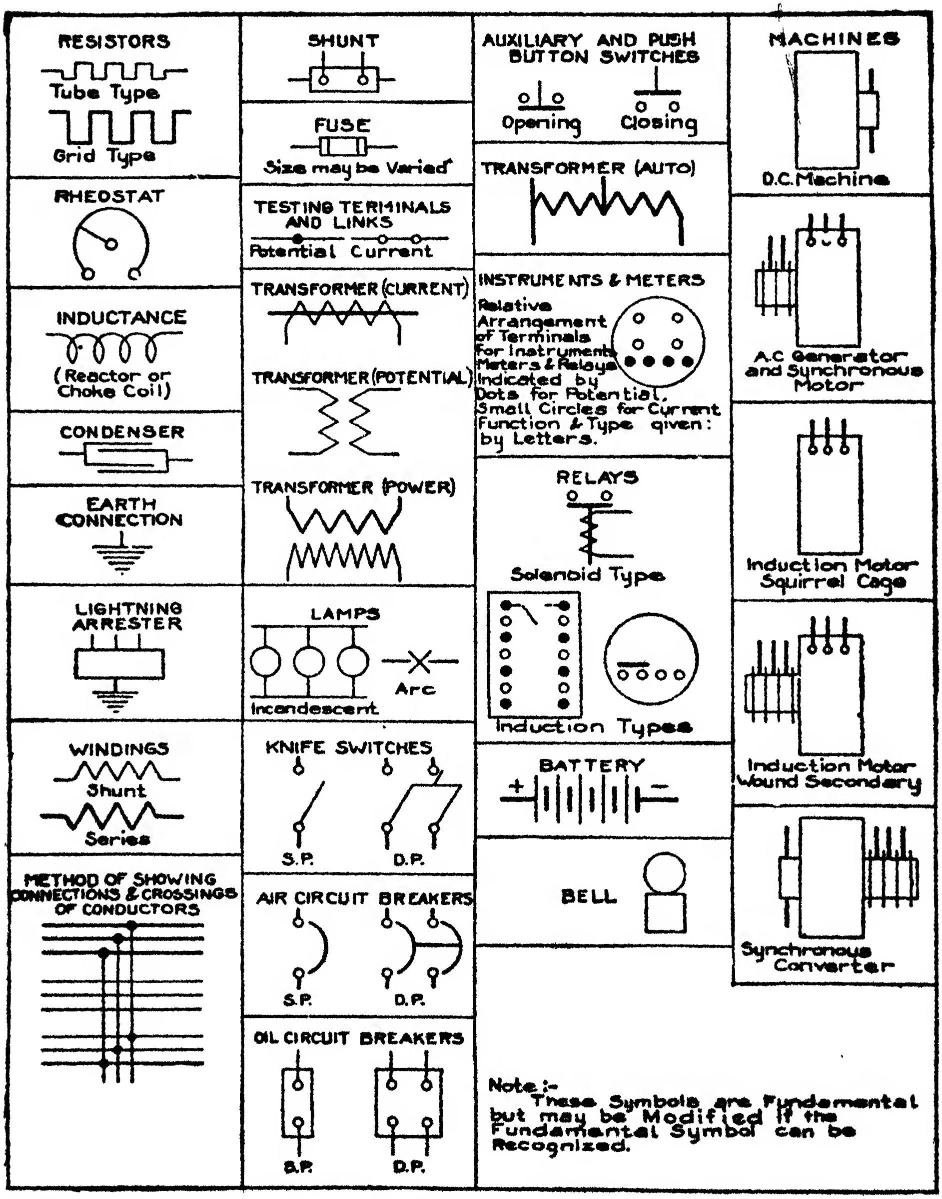
There is practically no limitation to the application of the *electrical, remote control switchboard*, if the necessary control course be available. It finds its greatest use, however, in plants of heavy capacities requiring electrically operated apparatus, or where the distance between the board and switching devices makes the application of hand operated apparatus undesirable.

Requirements.—Obviously, the *kva* capacity of the generating station, both present and ultimate, has a direct bearing on the limitations of the above class of switching equipment. In general the switching apparatus should be capable of interrupting the worst possible short circuits that can occur.

The amount of short circuit energy is dependent upon the *kva* capacity of synchronous apparatus connected to the system, its inherent reactance and the impedance of intervening transformer apparatus and connections.

The amount of energy that a circuit breaker would interrupt in the case of short circuit is not that indicated by the nominal rated capacity of the station, but the maximum power the synchronous apparatus is capable of passing through the breaker to a point just beyond, at the instant the breaker opens. Accordingly, the greater the duty demanded of the circuit breakers, the more rugged and heavier this piece of apparatus must be. This in turn usually determines the class of switchboard for the problem at hand. Therefore, only breakers of relatively small interrupting ability and small physical size can safely be mounted on the rear of panels, with the result that the direct control switchboards should be limited to stations of restricted current capacity and 2,500 volts or less. The reasons for these limitations lie chiefly in danger to operators, of high voltage and high powered apparatus when in close proximity with the low voltage control, instrument wiring, etc. All of these require inspection and occasional maintenance.

In other instances mechanical reasons may be the deciding factors.



FIGS. 4,653 to 4,691.—Standard symbols used in electrical connection diagrams of switchboards.

In general, it is recommended that no oil circuit breakers having a continuous current capacity of more than 800 amperes be used on direct controlled boards. Furthermore, no direct control *a.c.* type of board should be employed for stations having a capacity greater than 3,000 *kva.*

Such limitations naturally restrict the direct control board into what may be termed small capacity isolated generating stations or substations.

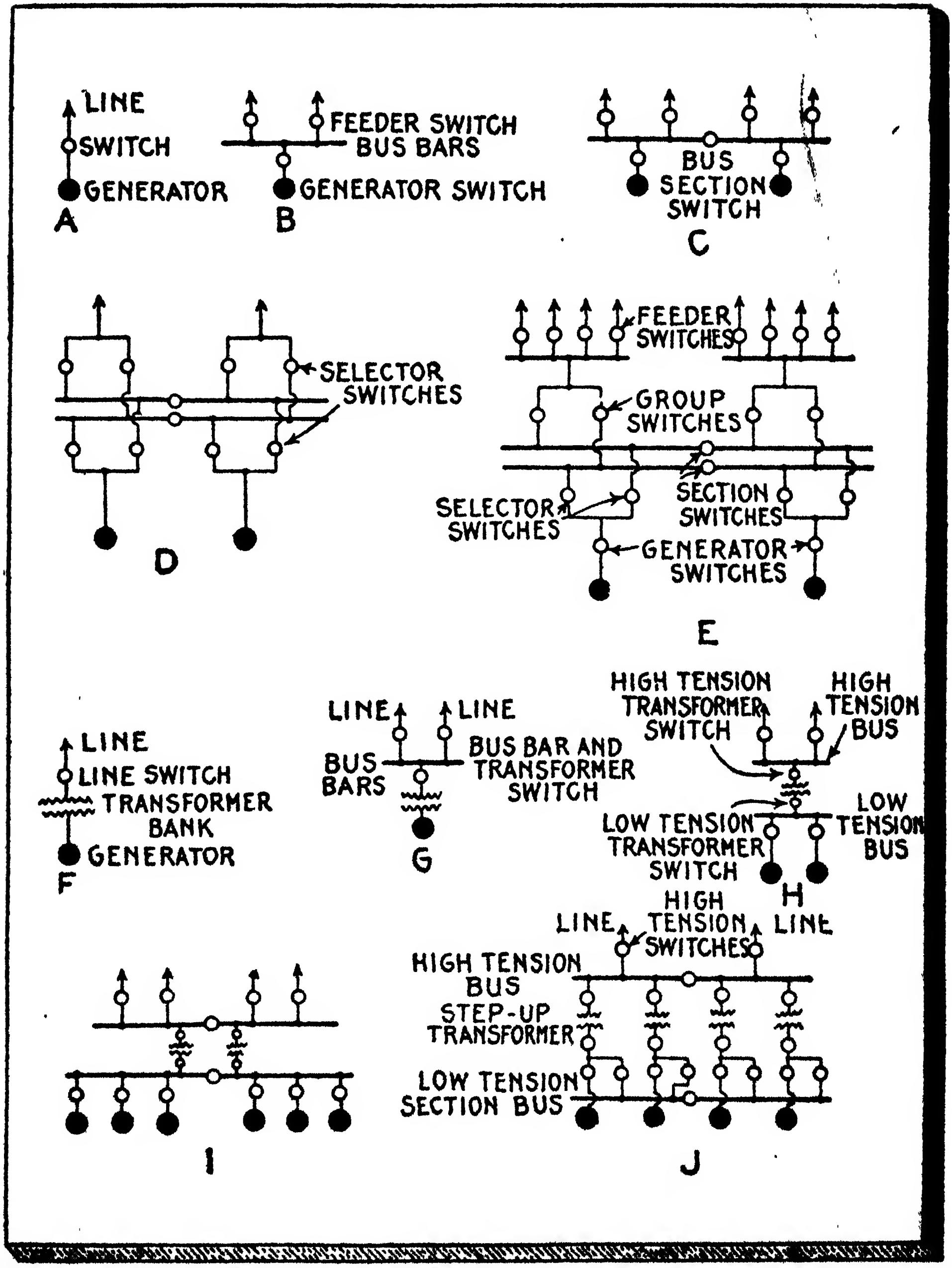
It is obvious that there is no sharp dividing line between the choice of a direct control board over a manual remote control board or between the manual remote and the electrical remote control board near the upper limit of the first two classes of switchboards.

Very often local factors will indicate the desirability of using the next higher class of board even though the amount of power controlled is within the usual limits of the lower class board. Generally speaking, the limitations of the direct control board are electrical while the manual remote control board limitations are largely of a mechanical nature.

Choice of Switching Arrangement.—Before attempting to select any particular type of switchboard, a complete *skeleton* or *single line* diagram of main connections for the proposed station should be prepared. After this has been studied carefully to see that it will meet operating requirements of the proposed project, calculations should then be made to determine the rupturing capacity required for the various oil circuit breakers. Such a study may bring out the desirability of modifying the scheme of main connections by the use of current limiting reactors or transformers to limit the concentration of power at any one particular spot in the system.

In making a choice of switching arrangement, probably the first item of consideration is whether this particular station is of relatively little importance or not with respect to the whole system.

If the entire station could be dispensed with for a short time without materially affecting service, then an inexpensive switching scheme would be justified. If the station be a major one and continuity of service be of prime importance, as it usually is, a more elaborate switching scheme must be contemplated.



Figs. 4,692 to 4,701.—Diagrams illustrating general principles of switchboard connections.

General Principles of Switchboard Connections.—The interconnection of generators, transformers, lines, bus bars, and switches with their relays, in modern switchboard practice-is shown by the diagrams, figs. 4,692 to 4,701. The figures being lettered **A** to **J** for simplicity, the generators are indicated by black discs, and the switches by open circles, while each heavy line represents a set of bus bars consisting of two or more bus bars according to the system of distribution. It will be understood, also, in this connection, that the number of pole of the switches and the type of switch will depend upon the particular system of distribution employed.

Diagram **A**, shows the simplest system, or one in which a single generator feeds directly into the line. There are no transformers or bus bars and only one switch is sufficient.

In **B**, a single generator supplies two or more feeders through a single set of bus bars, requiring a switch for each feeder, and a single generator switch.

In **C**, two generators are required and the addition of a bus section switch.

D, represents a number of generators supplying two independent circuits. The additional set of bus bars employed for this purpose necessitates an additional bus section switch, and also additional selector switches for both feeders and generators.

E, shows a standard system of connection for a city street railway system having a large number of feeders.

This arrangement allows any group of feeders to be supplied from any group of generators.

It also permits the addition of a generator switch for each generator.

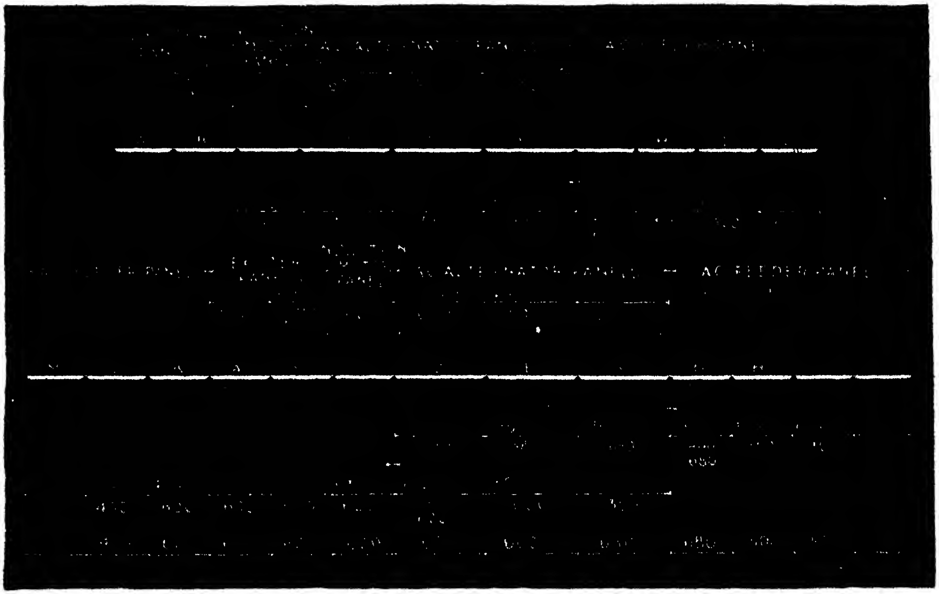
F, represents the simplest system with transformers.

It requires a single generator transformer bank, switch and line. The arrangement as shown at **F**, is used where a number of plants supply the same system.

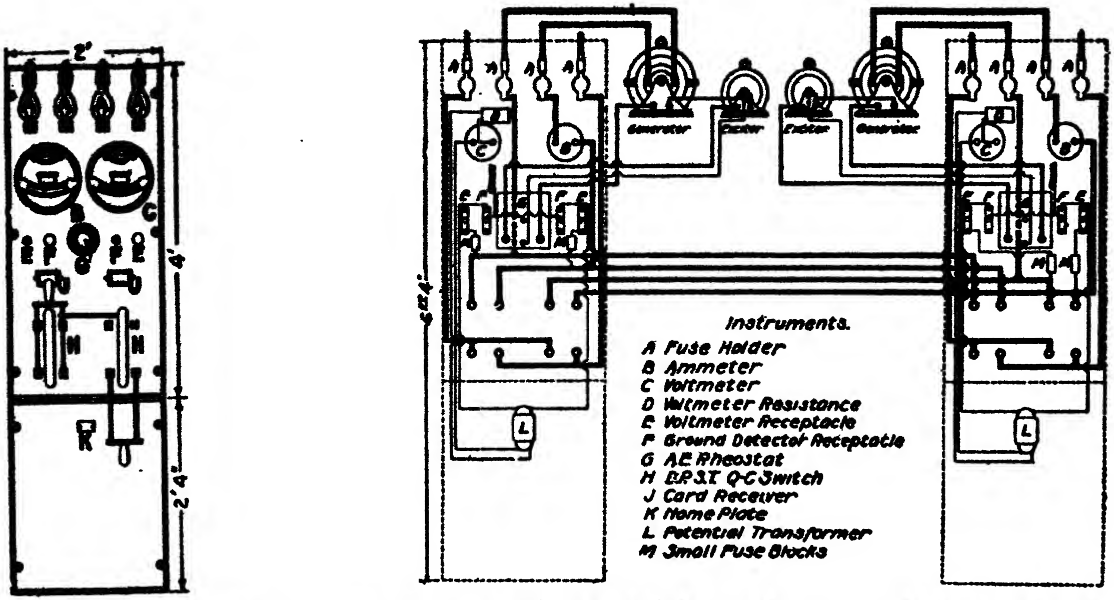
G, represents a system having more than one line.

In this case a bus bar and transformer switch are used on the high tension side.

H, shows a number of generators connected to a set of low tension bus bars through generator switches, and employing a low tension transformer switch.



FIGS. 4,702 and 4,703.—Diagrams illustrating ***a simple method of determining bus capacity*** as suggested by the General Electric Co. Fig. 4,702 relates to any panel; the method is as follows: *1.* Make a rough plan of the *entire board*, regardless of the number of panels to be ordered. *The order of panels* shown is recommended, it being most economical of copper and best adapted to future extensions. *2.* To avoid confusion keep on one side of board everything pertaining to exciter buses, and on other side everything pertaining to A.C. buses. *3.* With single lines represent the exciter and A.C. buses across such panels as they actually extend and by means of arrows indicate that portion of each bus which is connected to feeders and that portion which is connected to generators. *Remember that "Generator" and "Feeder" arrows must always point toward each other*, otherwise the rules given below do not hold. Note also that the field circuits of alternator panels are treated as D.C. feeders for the exciter bus. *4.* On each panel mark its ampere rating, that is, the maximum current it supplies to or takes from the bus. For A.C. alternator panels the D.C. rating is the excitation of the machines. *5.* Apply the following rules *consecutively*, and note their application in fig. 4,702. (For the sake of clearness ampere ratings are shown in light face type and bus capacities in large type.) *A. Always begin with the tail of the arrow and treat "generator" and "feeder" sections of the bus separately. B. Bus capacity for first panel = ampere rating of panel. C. Bus capacity for each succeeding panel = ampere rating of panel* plus *bus capacity for preceding panel.* (See sums marked above the buses in fig. 4,702.) *D. For a panel not connected to a bus extending across it, use the smaller value of the bus capacities already obtained for the two adjoining panels.* (See exciter bus for panel C.) *E. The bus capacity for any feeder panel need not exceed the maximum for the generator panels* (see A.C. bus for panel G) *and vice versa* (see exciter bus for panel B). Hence the corrections made in values obtained by applying rules *B* and *C*. The arrangement of panels shown in fig. 4,702 is the one which is mostly used. The above method may, however, be applied to other arrangements, one of which is shown in fig. 4,703. Here the generators must feed both ways to the feeders at either end of the board so that in determining A.C. bus capacities it is necessary to first consider the generators with the feeders at one end, and then with the feeders at the other end as shown by the dotted A.C. buses. The required bus capacities are then obtained by taking the maximum values for the two cases.

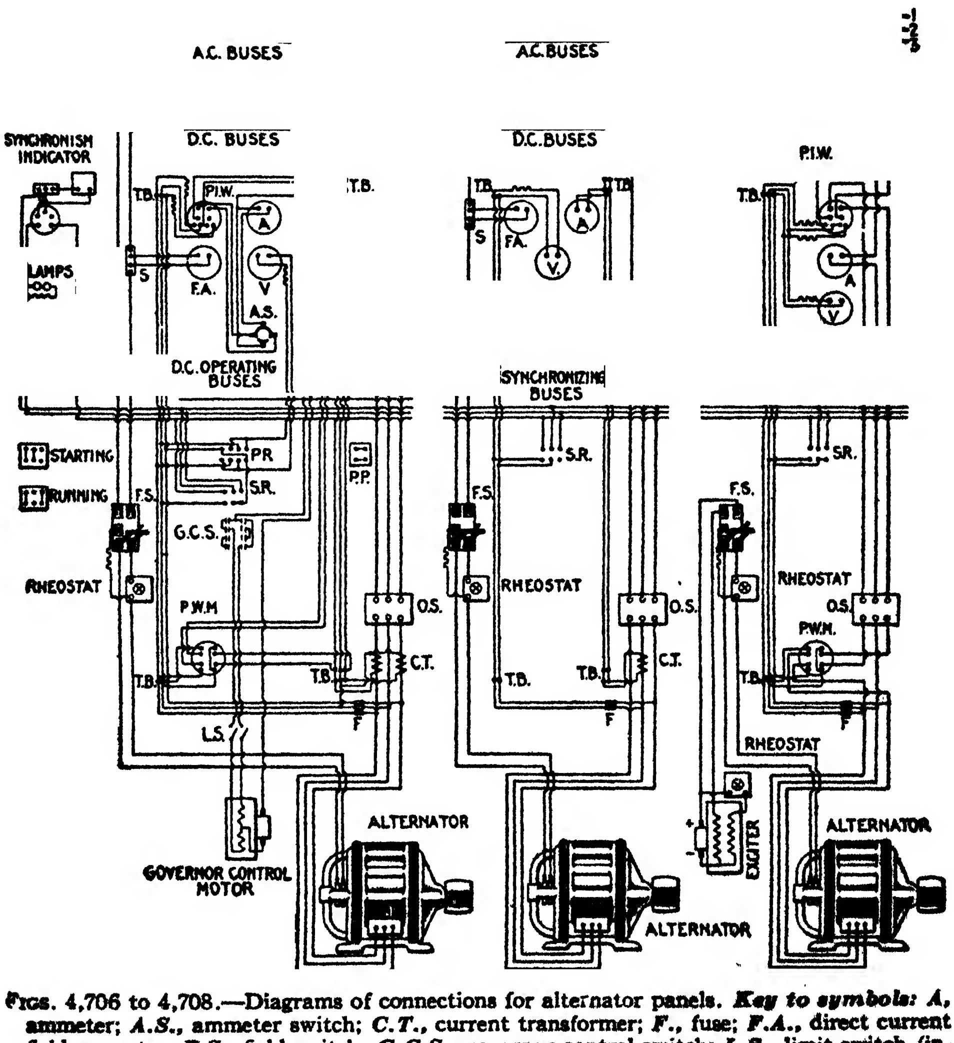


FIGS. 4,704 and 4,705.—Typical switchboard panel for one alternator and one transfer circuit. Diagram showing dimensions, arrangement of instruments on board, and method of wiring. The different forms of standard alternating current switchboard panels for single phase circuits are designed to fulfill all the usual requirements of switchboards for this class of work.

I, shows the connections of a system having a large number of feeders supplied by several small generators. In this case, the plant is divided into two parts, each of which may be operated independently.

J, represents the arrangement usually employed in modern plants where the generator capacity is large enough to permit of a generator transformer unit combination with two outgoing lines. By operating in parallel on the high tension side only, any generator can be run with any transformer. The whole plant can be run in parallel, or the two parts can be run separately.

Switchboard Panels.—The term "panel" means the slab of marble or slate upon which is mounted the switches, and the indicating and controlling devices. There are usually several



Figs. 4,706 to 4,708.—Diagrams of connections for alternator panels. ***Key to symbols: A,*** ammeter; *A.S.,* ammeter switch; *C.T.,* current transformer; *F.,* fuse; *F.A.,* direct current field ammeter; *F.S.,* field switch; *G.C.S.,* governor control switch; *L.S.,* limit switch (included with governor motor); *O.S.,* oil switch; *P.I.W.,* polyphase indicating watt meter; *P.W.M.,* polyphase watt hour meter; *P.R.,* pressure receptacle; *P.P.,* pressure plug; ***Rheo.,*** rheostat; *S.,* shunt; *S.R.,* synchronizing receptacle; *S.P.,* synchronizing plugs; *T.B.,* terminal board for instrument leads; *V.,* alternating current volt meter.

panels comprising switchboards of moderate or large size, these panels being classified according to the division of the system that they control, as for instance:

1. Generator panel.
2. Feeder panel.
3. Regulator panel, etc.

In construction, the marble or slate should be free from metallic veins, and for pressures above, say, 600 volts, live connections, terminals, etc., should preferably be insulated from the panels by ebonite, mica, or removed from them altogether, as is generally the case with the alternating gear where the switches are of the oil type.

The bus bars and connections should be supported by the framework at the back of the board, or in separate cells, and the instruments should be operated at low pressure through instrument transformers.

The panels are generally held in position by bolting them to an angle iron, or a strip iron frame work behind them.

Generator Panel.—This section of a switchboard carries the instruments and apparatus for measuring and electrically controlling the generators. On a well designed switchboard each generator has, as a rule, its own panel.

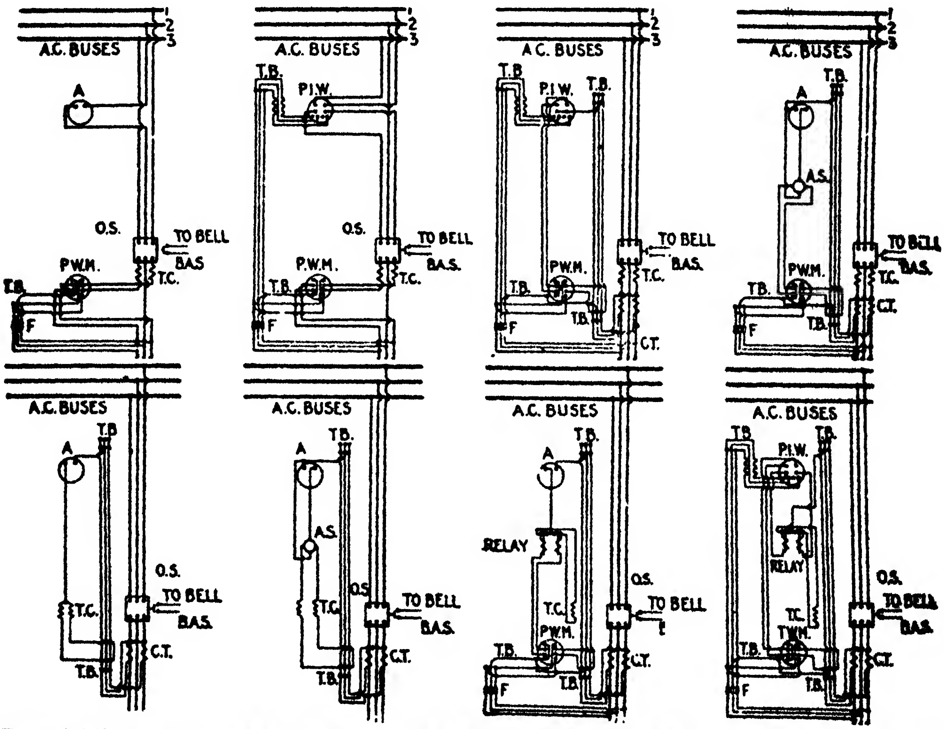
In the case of a high pressure alternating current plant of considerable size, the bus bars, oil switches, and the current and pressure transformers are generally mounted either in stoneware cells, or built on a framework in a space guarded by expanded metal walls, and no high pressure apparatus of any sort is brought on to the panels themselves.

Feeder Panel.—The indicating and control apparatus for a feeder circuit is assembled on a panel called the feeder panel.

The most common equipment in the case of a direct current feeder panel comprises an ammeter, a double pole switch, and double pole fuses or instead of the fuses, a circuit breaker on one

or both poles; in the case of a traction feeder, a choke coil and a lightning arrester are often added.

The equipment of a typical high pressure three phase feeder panel is an ammeter (sometimes three ammeters, one in each phase) operated by a current transformer, and oil brake switch



FIGS. 4,709 to 4,716.—Diagrams of connections for three phase feeder panels. *Key to symbols:* A, ammeter; A.S., three way ammeter switch; B.A.S., bell alarm switch; C.T., current transformer; F, fuse; O.S., oil switch; P.I.W., polyphase indicating watt meter; P.W.M., polyphase watt hour meter; T.B., terminal board; T.C., trip coils for oil switch.

with two overload release coils, or three if the neutral of the circuit be earthed, the releases being operated by current transformers.

Truck Type Switchboards.—Recently another form of switchboard arrangement has come into use for certain classes of

service and is commonly known as the truck type panel as shown in figs. 4,717 to 4,722. The bus bars are mounted in a steel housing and the panel, circuit breaker and instrument transformers are on a removable truck. The housing and truck carry disconnecting devices for both primary and secondary circuits. The truck is mechanically interlocked with the housing so that it cannot be inserted nor withdrawn unless the circuit breaker be opened. The breaker cannot be closed unless the truck is in the operating or in the disconnected position.

FIG. 4,717.—**Westinghouse small truck type switchboard: front view cell.**

Truck type panels are equipped with either manually operated or electrically operated circuit breakers as may be desired, and they are applicable for any service connected with the generation or distribution of electrical power within the breaker interrupting rating.

Fig. 4,718.—***Westinghouse truck type switchboard construction.*** 1, side view showing terminal.

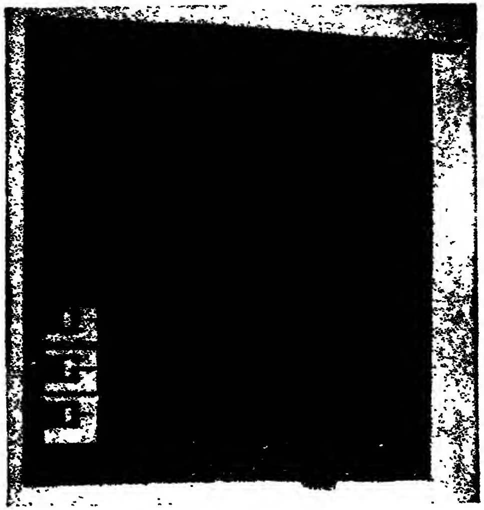


Fig. 4,719.—***Westinghouse truck type switchboard construction.*** 2 rear view of truck.

The panels are usually of steel with the result that larger breakers of the hand operated type can be used than is the case in the usual direct control board.

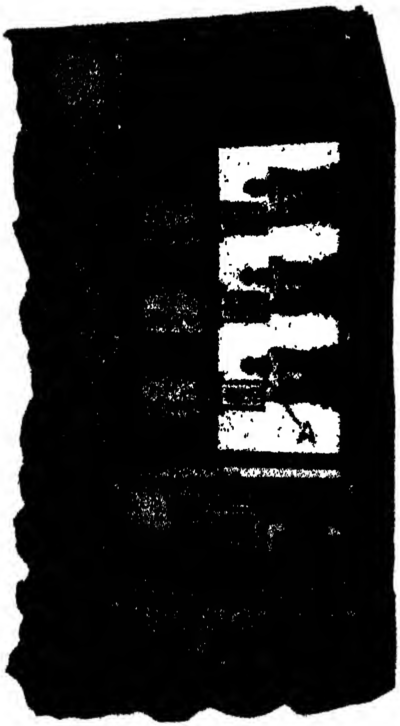
The principal advantages of the enclosed truck panels are:

1. All live parts are totally enclosed and mechanical interlocks prevent mistakes in operation.

2. All parts requiring inspection are on a removable truck which is "dead" on all sides when removed from the housing.

3. Automatic shutters cover the opening through which the main disconnecting contacts pass so that the truck compartment is safe to enter when the truck is removed.

4. A truck may be replaced by a spare one in a few moments' time and the circuit breaker inspected without a prolonged interruption of service. Maintenance is thus made both safe and easy.



5. The installation work for the purchaser is, in general, much less than for ordinary manual direct control board as the equipment is shipped completely assembled in units. The purchaser merely has to fasten the housing to the floor steel work, install the bus bars, make cable connections and fill the circuit breaker tank with oil.

This type of panel equipment is becoming very popular for industrial sub-stations when the grade of switchboard attendant is not of the highest order.

It is also used to quite an extent for station auxiliary circuits in power houses where time is an important factor in restoring service after an interruption.

FIG. 4,720.—***Westinghouse truck type switchboard construction.*** 3 bus and lead compartments. Barriers removed.

NOTE.—***Truck type switchboards*** originated in Europe and England where the laws and regulations governing safety features for the protection of employees are very stringent. The progress of the safety first movement resulting in the enactment of laws in many states has created a strong demand for them in this country. The complete protection from electrical hazard allows the employment of cheap, unskilled operators with the degree of safety implied by the spirit of the safety first movement, if they be sufficiently intelligent to follow instructions for operating the switches.

The truck type switchboards are often of the electrically operated type with the usual separate control panels similar to any electrically operated board. The breakers with associated instrument transformers are located on trucks rather than on permanent frame work or cell structure.

Theatre Switchboards.—The lighting requirements of the various classes of show houses differ greatly, and no one type of control equipment can be expected to fulfill all conditions with maximum satisfaction. Several types of switchboards are necessary to meet the requirements of the different classes of theatre; the latter may be classified as

FIGS. 4,721 and 4,722.—*Westinghouse truck type switchboard construction.* 4, interior view of cell. Fig. 4,721, shutter closed; fig. 4,722, shutter held open. *In operation* when the truck is withdrawn from its cell, the live stationary contacts are not left exposed as in most designs. Shutters automatically cover all the high tension live parts preventing accidental contact with them. When the truck is pushed into its cell, the rollers on the truck engage the shutter levers on the cell; and the shutters are opened to permit engagement of the contacts.

1. Legitimate.
2. Vaudeville.
3. Motion Picture,
   etc.

The several types of switchboards designed to meet the varied requirements are

1. Direct control switchboards.
2. Pre-selective switchboards.
   a. Two screw.
   b. Multi-screw.

Direct control switchboards.—

Tumbler type direct control boards can be used in school auditoriums, small motion picture theatres, churches, and in other places where it is possible to provide skilled attendance for the switchboard, or where the cost of equipment must be kept low.

To obtain maximum results with a board of this type requires a first class operator, and better satisfaction will usually result, with the elimination of possibilities of errors, by the application of a pre-set board. The operating possibilities of these boards are such that independent pre-sets can be made in each color group.

Each group is under the control of a master switch, which can feed energy to the complete group of circuits in its color group, or to any desired selection of circuits in the group.

The circuits can be arranged so that the complete lighting is controlled by a master switch at the board. Each color group taken care of on this type of board is normally provided with its own dimmers. The circuits are conveniently grouped so that economy of material and apparatus can be carried out effectively. The constant circuits can be controlled from the switchboard.

Pre-selective switchboards.—

The pre-selective board allows the operator to set up the lighting for a second scene or act, while the first scene lighting is being used. It is well adapted for use in vaudeville theatres,

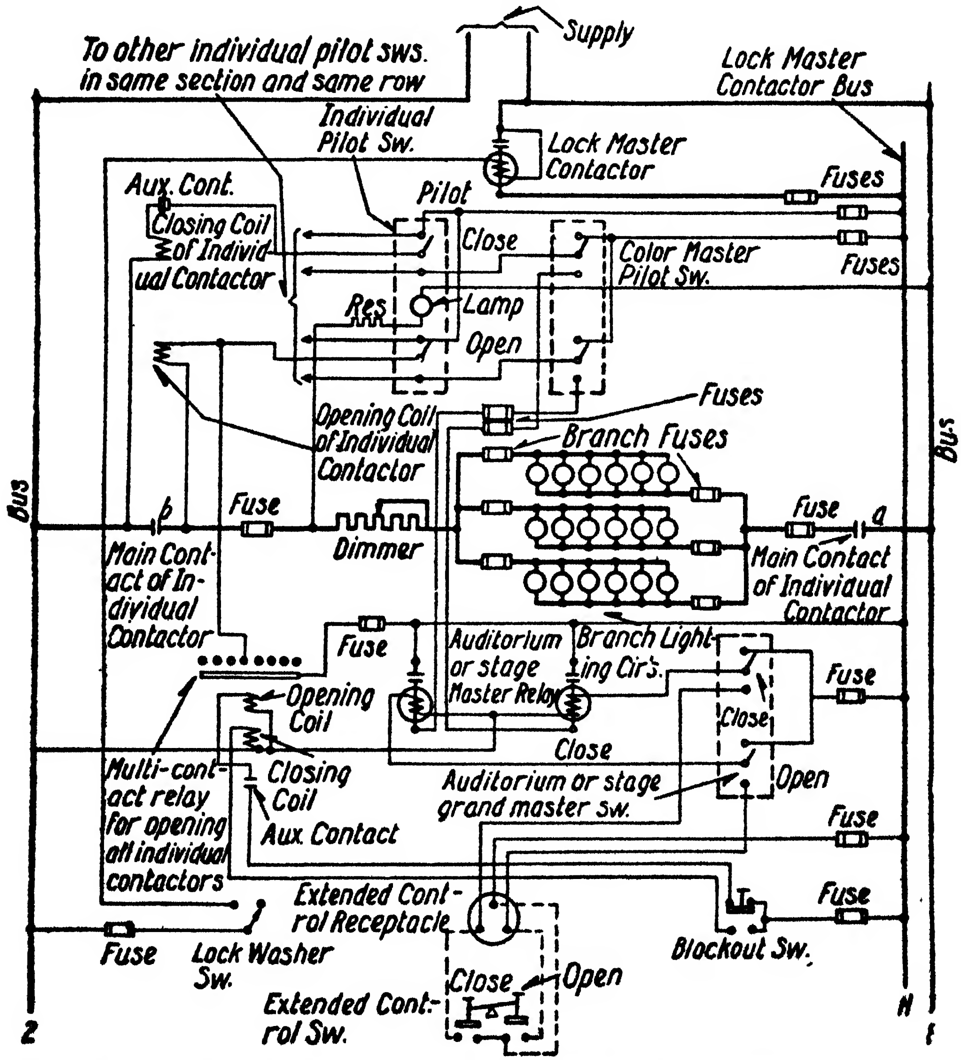


FIG. 4,723.—Westinghouse diagram of connections of a pre-selective type theatre switchboard.

because in this service, it is not expedient to set up the lighting for more than one scene in advance, owing to the nature of the program.

In the hands of a skilled operator the pre-selective board provides a very satisfactory control for this service, with a lower energy consumption, due to the fact that the contactors are latched in, rather than held in by an electro magnet.

On the stage pilot board the lighting for one scene or act can be pre-selected in any combination of colors and at any time that scene lighting may be thrown on by the main master switch. This energizes the coil of the master contactor, which at the moment of closing feeds energy through all the control circuits set up for the scene. The contactors for these circuits then close, and are latched in that position. The pilot switches on the stage pilot board are then free so that a pre-selection can be made during the showing of the first scene for the lighting to be used during the second scene.

The switchboard equipment consists essentially of the following three parts:

1. Pilot board.
2. Contactor board.
3. Magazine panel.

The pilot board incorporates the dimmer bank, the dimmer operating mechanism and all switching apparatus for producing the lighting effects.

The dimmer bank is mounted in a heavy angle iron frame. Each dimmer or set of dimmers for one circuit, depending on the wattage, is provided with a handle for individual operation. The dimmer bank is usually divided into two principal parts—house and stage. Three or four color groups are usually furnished and the dimmers and switches pertaining to one color are mounted in a horizontal row, while the dimmers and switches pertaining to the same circuit are mounted in a vertical sequence, so that for any circuit all its color controls are in a vertical row with the white control at the top, amber next, then red and blue.

The electrical control scheme is arranged along the same lines as the dimmer control, that is, there is an individual pilot switch for each circuit, a color master switch located at the end of each color group and a stage main and house main switch in a central and convenient position.

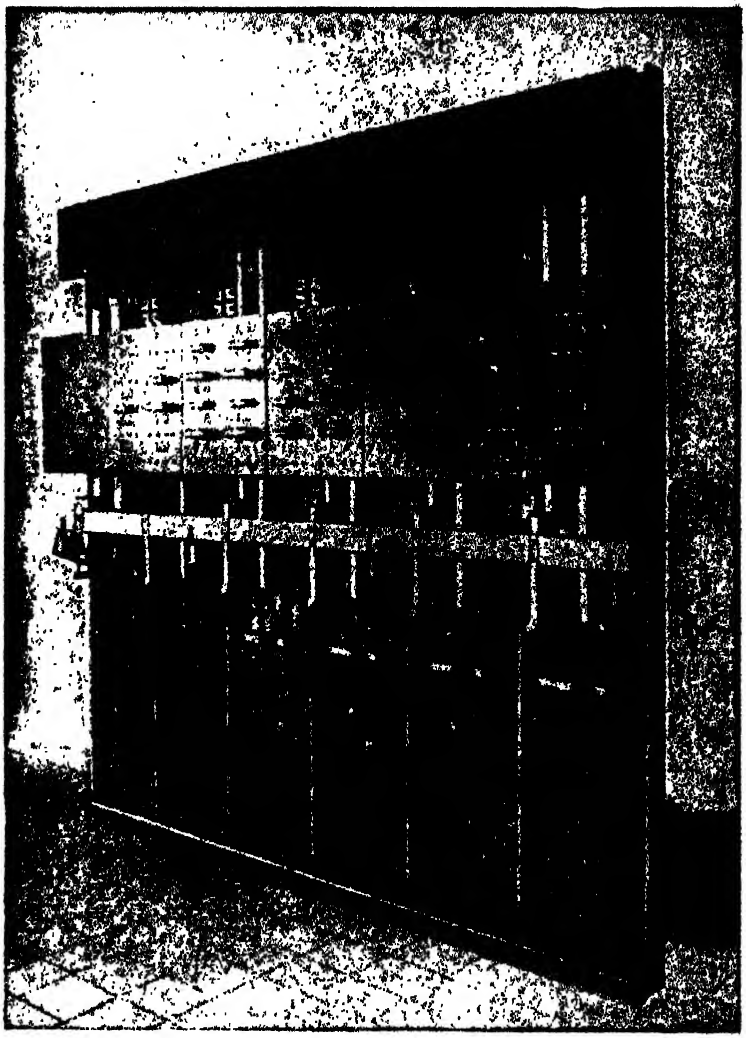


FIG. 4,724.—Rear view of Westinghouse contactor board for Keith Theatre, Boston, Mass. This view shows how the magazine panel may be mounted.

The various push buttons and switches for the constant circuits to dressing rooms, etc., are placed in convenient and suitable locations.

The contactor board contactors are arranged so that their position corresponds with the position of their circuit controls on the pilot board, which facilitates inspection.

The contactor board is usually placed in a separate room directly below the pilot board.

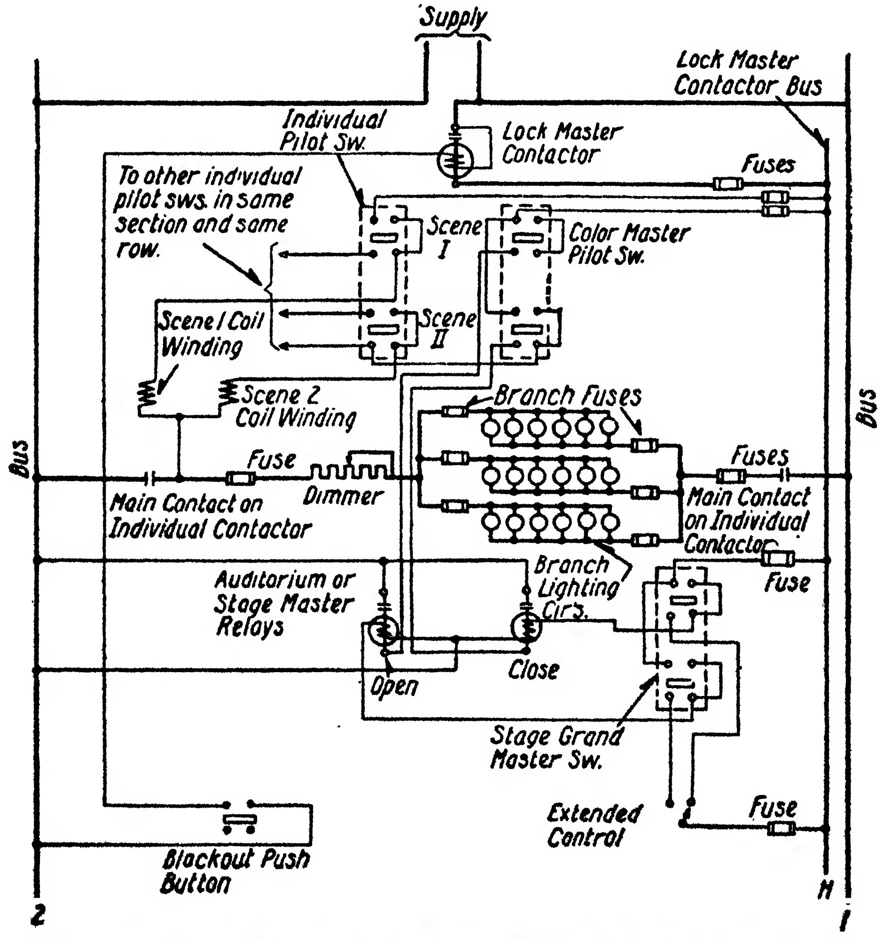


FIG. 4,725.—Diagram of connections of Westinghouse two scene pre-set switchboard.

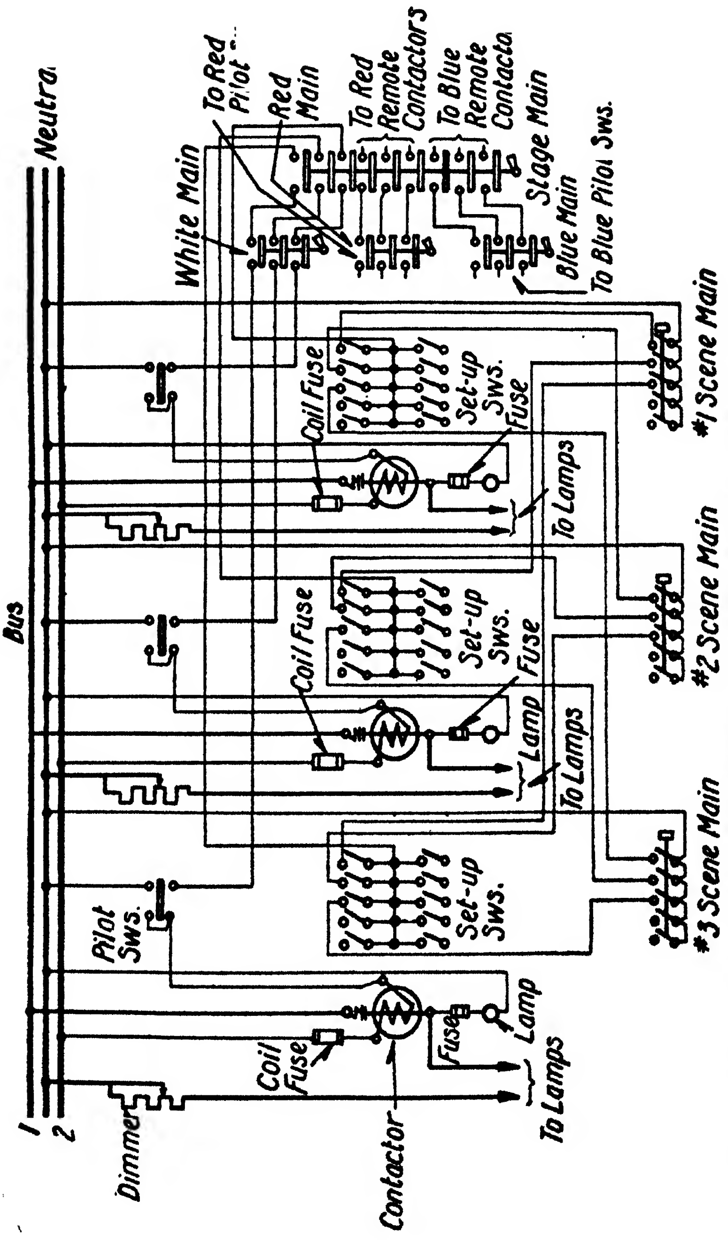


FIG. 4,726.—Diagram of connections of Westinghouse multi-pre-set theatre switchboard.

Where a separate magazine panel containing fuses for the individual circuits is provided, a slate base with main fuses for each contactor may be mounted directly in back of the contactor board as shown in fig. 4,724.

Where a solidly grounded neutral is permissible, it is possible to simplify the equipment greatly by omitting the magazine panel and mounting the individual circuit fuses, directly below the contactors.

In the multi-pre-set switchboard, all the controls for a single circuit, which include the pilot switch, pilot lamp, pre-set switches, and circuit dimmers, are mounted together on a small section of the board.

The number of pre-set switches is dependent upon the number of scenes that the board can handle, that is, if the board be ten scene, there will be 10 pre-set switches for each circuit.

The pre-set switches are arranged in horizontal rows with five switches to the row. To set up a circuit, the pre-set switches for the scenes in which that circuit is to be used are flipped to the "on" position, and for the scenes where that circuit is not to be used they are moved to the "off" position. This procedure is followed for all the circuits on the board, and when completed the board is ready for the performance. The setting up process can be done best at a rehearsal, and the effects can then be given serious attention and changed until just the right lighting is secured.

All the lighting for scene 1 can be fixed by setting all the scene 1 pre-set switches, then scene 2 can be taken care of, and so on for the entire production.

The pilot switch handles are pushed up into the set up position, closing the lower switch contacts. This is the position in which they are ordinarily left, for a production, and it places the circuit under the control of the color master switch.

Pushing the color master switch handle up then places the color circuits under the control of the scene grand master switches.

There is a scene grand master switch for each scene that can be set up, thus a ten scene pre-set board has ten scene grand master switches. There is no limitation to the manner in which the scene grand master switches can be manipulated. Any one can be thrown on at any time, and any number can be closed at the same time.

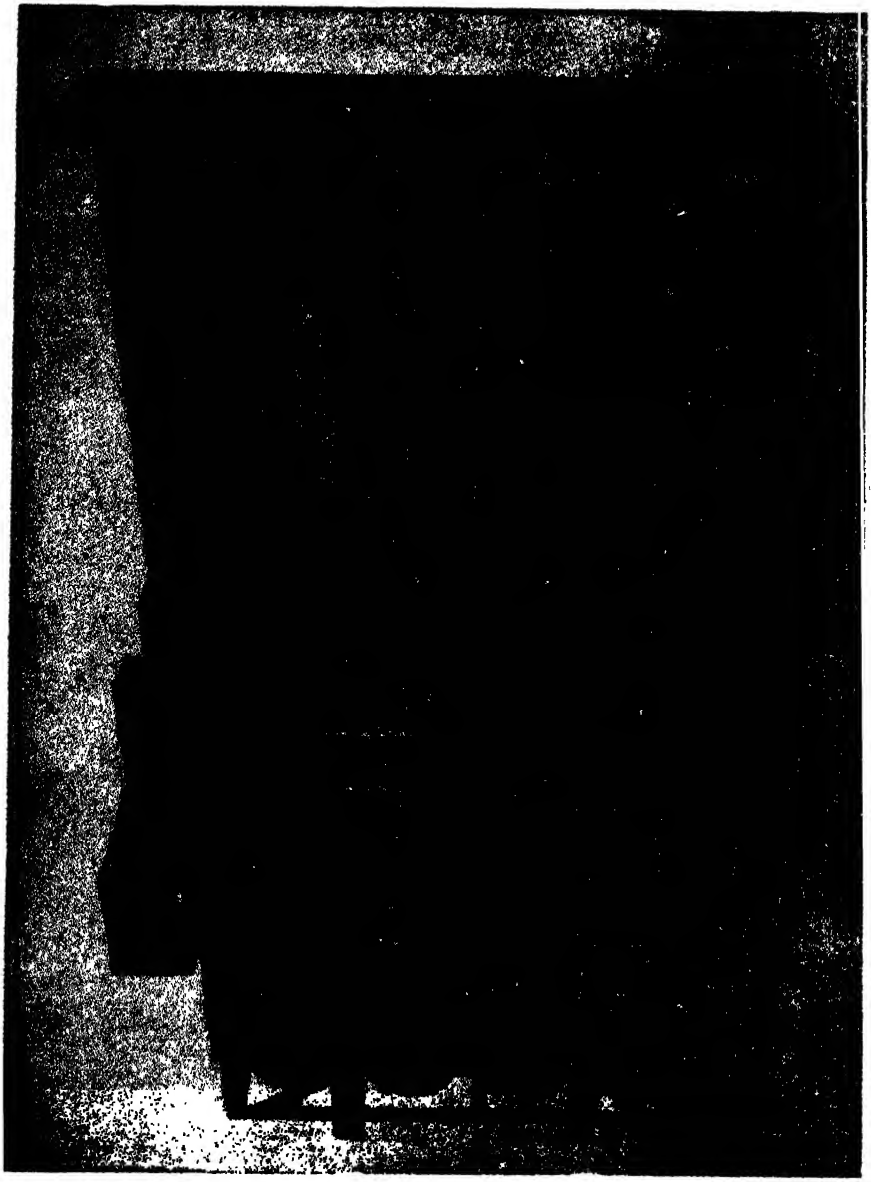


FIG. 4,727.—Rear view of Westinghouse multi-pre-set theatre switchboard, showing the mounting of the dimmers and the wiring troughs.

To change from one scene to another without a "blackout," close the scene grand master switch for the following scene before opening the one for the scene in progress.

If a "blackout" be desired, open the scene grand master switch for the scene in progress, and then close the one for the scene wanted. A scene may be repeated as often and whenever desired.

The color masters, color master dimmers, the scene grand master switches, and slow motion master dimmer hand wheel are all located at the center of the board so that the operator does not have to run back and forth in handling the lighting. All essential controls are in easy reach from one position.

The individual circuit dimmers can be interlocked with the color master and the color master in turn interlocked with the slow motion master hand wheel. A cross control is provided so that each color master handle can be interlocked in such a way as to brighten or dim the lighting of its color group as may be desired irrespective of the direction of motion of the other color dimmers.

A "hot-bus" connection is provided for each circuit. By closing the upper switch contacts for a circuit, that circuit is thrown on the "hot-bus" and lighted. It remains lighted regardless of the position of the master controls.

With the entire lighting for a production set up, the operator can devote his whole attention to the operation of the dimmers. There is no haste, and possibilities for distracting errors are very remote. Once the lighting has been set up, no changes are necessary in the setting until a change occurs in the program, which may be a week or longer, depending upon the program.

TEST QUESTIONS

1. *Give a classification of switchboards.*
2. *How are foundations constructed for switchboards?*
3. *Explain how to erect a panel for a switchboard.*
4. *Explain how shimming is done.*
5. *Describe the frame structure for switchboards.*
6. *Give a list of various classes of* a.c. *switchboards.*
7. *What is a direct control switchboard?*

8. *Describe a remote control switchboard.*
9. *Name three forms of electrically controlled switchboards.*
10. *Give at length the various requirements for switchboards.*
11. *How is the choice of switching arrangement determined?*
12. *Give the general principles of switchboard connections.*
13. *Give a simple method for determining bus capacity.*
14. *Define the term "panel" as applied to switchboards.*
15. *Name three classes of panels.*
16. *Describe the generator panel.*
17. *What apparatus is placed on the feeder panel?*
18. *Describe a regulator panel.*

CHAPTER 89

Power Stations

The term *central* or *power station* is usually applied to any building containing an installation of machinery for the conversion of energy from one form into another form. There are three general classes of power station:

1. Central stations.
2. Sub-stations.*
3. Isolated plants.

Power stations may be classified

1. With respect to their function, as

   a. Generating stations.
   b. Distributing stations.
   c. Converting stations.

2. With respect to the kind of power used in generating the electric current, as

   a. Steam electric.
   b. Hydro-electric.
   c. Gas electric, etc.

*NOTE.—*Sub-stations* and *isolated plants* are presented in separate chapters.

3. With respect to the distribution of power, as
   a. Generation and distribution voltages the same.
   b. Generation voltage lower than distribution voltage.
   c. Distribution at several voltages, one of which is the same as the generation voltage.

4. With respect to the kind of current supplied, as
   a. Direct.

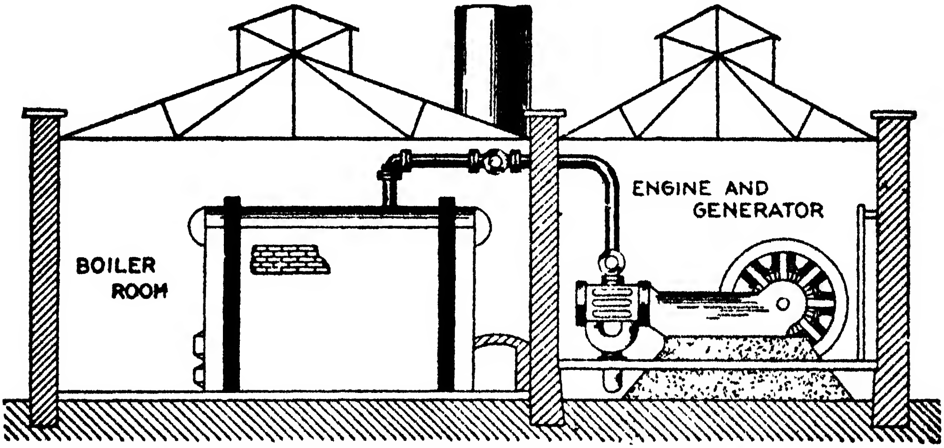


FIG. 4,728.—Elevation of small station with direct drive, showing arrangement of the boiler and engine, piping, etc.

   b. Alternating.
   c. Direct and alternating.

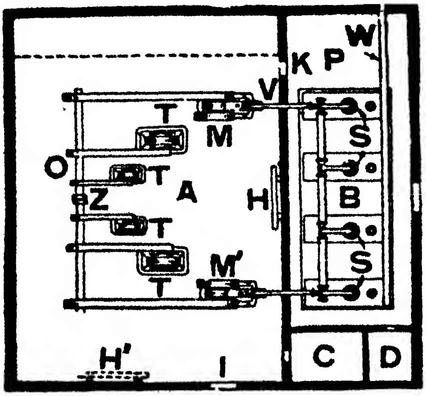
Central Stations.—It must be evident that the general type of central station to be adapted to a given case, that is to say, the general character of the machinery to be installed depends upon the kind of natural energy available for conversion into electrical energy, and the character of the electrical energy required by the consumers.

The general tendency is toward larger stations, and the interlocking of the systems located in different localities.

The reasons for this is because the investment cost per *kw*. generated decreases as the size of the station increases. also by taking advantage of the

interconnection of stations the most efficient means of generation of power may be employed as, by steam, water or gas engine power.

Location of Central Stations.—Usually central stations should be so located that the average loss of voltage in over-



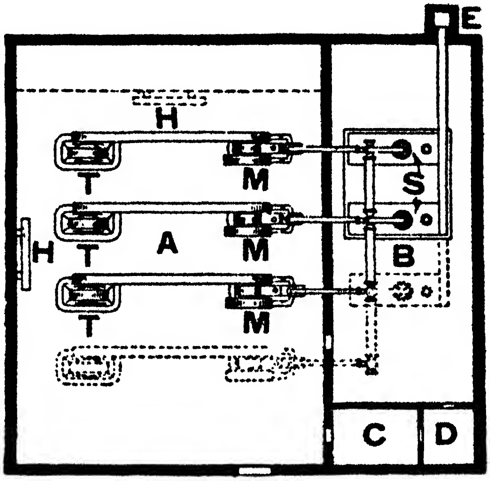


FIG. 4,729.—Floor plan of station having belted drive with countershaft A, engine and dynamo urn; B, boiler room; C, office; D, store room; E, chimney connected with the boilers by flue W; S,S, boilers; V,V, steam pipes; M,M, engine; O, countershaft; T,T,T,T, generators; H, switch board. A pulley may be mounted on the countershaft O, with a friction clutch. A jaw clutch may also be provided at Z, thus permitting the shaft O, to be divided into two sections. It is therefore possible by this arrangement to cause either of the engines to drive any one of the generators, or all of them, or both of the engines to drive all of the generators simultaneously.

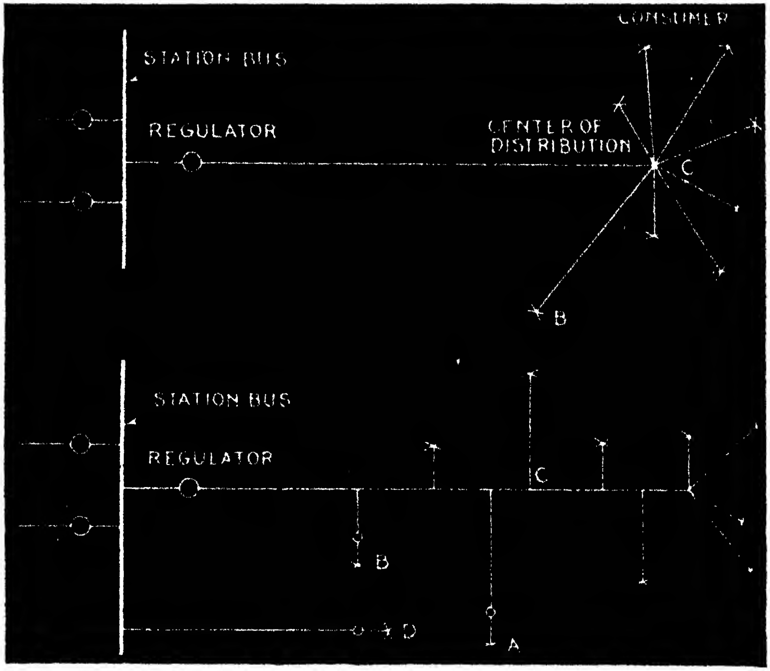
FIG. 4,730.—Plan of electrical station with belt drive without counter shaft. The installation here represented consists of two boilers, S,S, and three sets of engines and generators, T, M, etc. Sufficient allowance has been made in the plans, however, for future increase of business, as additional space has been provided for an extra engine and generator set, as indicated by the dotted lines. Other reference letters are the same as in fig. 4,729.

coming the resistance of the lines is a minimum, and this point is located at the center of gravity of the system. In fig. 4,731 is shown a graphical method of locating this important spot.

Suppose a rough canvass of prospective consumers in a district to be supplied with electric light or power shows the principal loads to be located at A, B, C, D, E, etc., and for simplicity assume that these loads will be approximately equal, so that each may be denoted by 1 for example:

The relative locations of A,B,C,D,E, etc., should be drawn to scale (say 1 inch to the 1,000 feet) after which the problem resolves itself into finding the location of the station with respect to this scale.

The solution consists in first finding the center of gravity of any two of the loads, such as those at A and B. Since each of these is 1, they will together have the same effect on the system as the resultant load of 1 and 1, or 2, located at their center of gravity, this point being so chosen that the



FIGS. 4,731 and 4,732 —Graphical method of determining the *center of gravity* of a system in locating the central station.

product of the loads by their respective distances from this point will in both cases be equal.

The loads being equal in this case the distances must be equal in order that the products be the same, so that the center of gravity of A+B is at G, which point is midway between A and B.

Considering, next, the resultant load of 2 at G, and the load of 1 at C, the resultant load at the center of gravity of these will be 3, and this must be situated at a distance of two units from C, and one unit from G, so that the

distance 2 times the load 1 at C, equals the distance 1 times the load 2 at G. Having thus located the load 3 at H, the same method is followed in finding the load 4 at I. Then in like manner the resultant load 4 and the load 1 at E, gives a load 5 at S.

The point S being the last to be determined, represents, therefore, the position of the center of gravity of the entire system, and consequently the proper position of the plant in order to give the minimum loss of voltage on the lines.

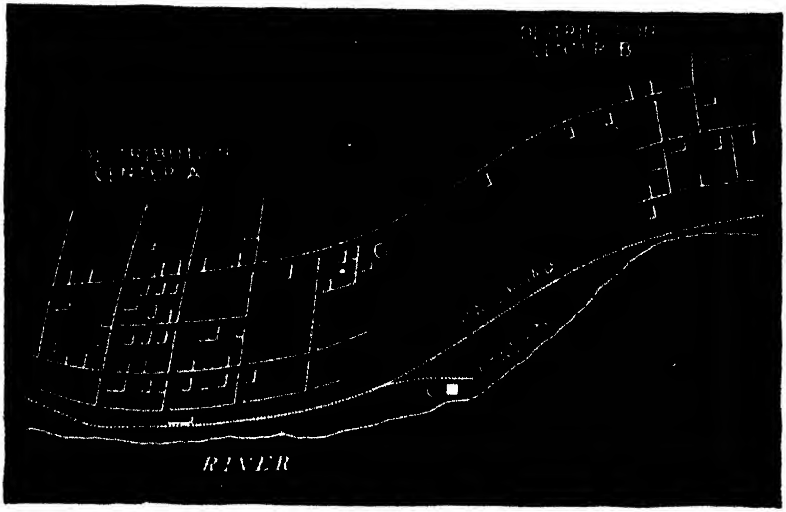


Fig. 4,733.—Station location. The figure shows two distribution centers as a town A, and suburb B, supplied with electricity from one station. For minimum cost of copper the location of the station would be at G, the center of gravity. However, it is very rarely that this is the best location. For instance at C, land is cheaper than at G, and there is room for future extension to the station, as shown by the dotted lines, whereas at G, only enough land is available for present requirements. Moreover C, is near the railroad where coal may be obtained without the expense of cartage, and being located at the river, the plant may be run condensing thus effecting considerable economy. The conditions may sometimes be such that any one of the advantages to be secured by locating the station at C, may more than offset the additional cost of copper.

The center of gravity as obtained in fig. 4,731 is very rarely the best location because other conditions, such as the price of land, difficulty of obtaining water, facilities for delivery of coal and removal of ashes, etc., may more than offset the minimum line losses and copper cost due to locating the station at the center of gravity of the system.

The more practical experience the designer has had, and the more common sense he possesses, the better is he equipped to handle the problem, as the solution is generally such that it cannot be worked out by any rule of thumb method.

The cost for the station site may be so high as to necessitate building or renting room at a considerable distance from the district to be supplied.

If the price of land selected for the station be high, the running expenses will be similarly affected, inasmuch as more interest must then be paid on the capital invested.

The price or rent of real estate might also in certain instances alter the proposed interior arrangement of the station, particularly so in the case of a company with small capital operating in a city where high prices prevail. In general, however, it may be stated that whatever effect the price of real estate would have upon the arrangement, operation and location of a central station it can quite readily and accurately be determined in advance.

With respect to the cost of land, room for future extension of the plant should be considered.

Although such additional space need not be purchased at the time of the original installation it is well, if possible, to make provision whereby it can be obtained at a reasonable figure when desired. The preliminary canvass of consumers will aid in deciding the amount of space advisable to allow for future extensions; as a rule, however, it is wise to count on the plant enlarging to not less than twice its original size, as often the dimensions have to be increased four and even six times those found sufficient at the beginning.

Another item to be considered in the location of a plant is its environments, as it may be regarded as a nuisance by those residing in the vicinity, occasioning many complaints and litigation.

Thus, if the plant be placed in a residential section of the community the smoke, noise and vibration of the machines may become a nuisance to the surrounding inhabitants, and eventually end in suits for damage against the company responsible for the same. For these and the other reasons just

given a company is sometimes forced to disregard entirely the location of a central station near the center of gravity of the system, and build at a considerable distance; such a proceeding would, if the distance be great, necessitate the installation of a high voltage system.

There might, however, be certain local laws in force restricting the use of high pressure currents on account of the danger resulting to life, that would prevent this solution of the problem. In such cases there could undoubtedly be found some site where the objections previously noted would be tolerated; thus, there would naturally be little objection to locating next to a stable or a factory of any description.

The matter of water supply is important because in a steam driven plant, water is used in the boilers for the production of

Fig. 4,734.—Example of central station located remote from the distributing center and furnishing alternating current at high pressure to a sub-station where the current is passed through step down transformers and supplied at moderate pressure to the distribution system. In some cases the sub-station contains also converters supplying direct current for battery-charging, electro-plating, etc.

steam by boiling, and if the engines be of the condensing type it is also used in the condenser for creating a vacuum into which the exhaust steam passes so as to increase the efficiency of the engine above what it would be if the exhaust steam were obliged to discharge into the comparatively high pressure of the atmosphere.

The force of this will be apparent by considering that the water consumption of the engine ordinarily is from 10 to 25 lbs. of "feed water" per horse power per hour, and the amount of "circulating water" required to maintain the vacuum is about 25 to 30 times the feed water, and in the case of turbines with their 28 or 29 inch vacuum, much more. For instance, a

1,000 horse power plant running on 15 lbs. of feed water and 30 to 1 circulating water would require $(1,000\times15)\times(30+1)=465,000$ lbs. or 55,822 gals. per hour at full capacity.

The quality and possibility of a scarcity of water supply also is important.

It is quite necessary that the water used in the boilers should be as free as possible from impurities, so as to prevent the deposition within them of any scale or sediment. The quality of the water used for condensing purposes, however, is not quite so important, although the purer it is the better.

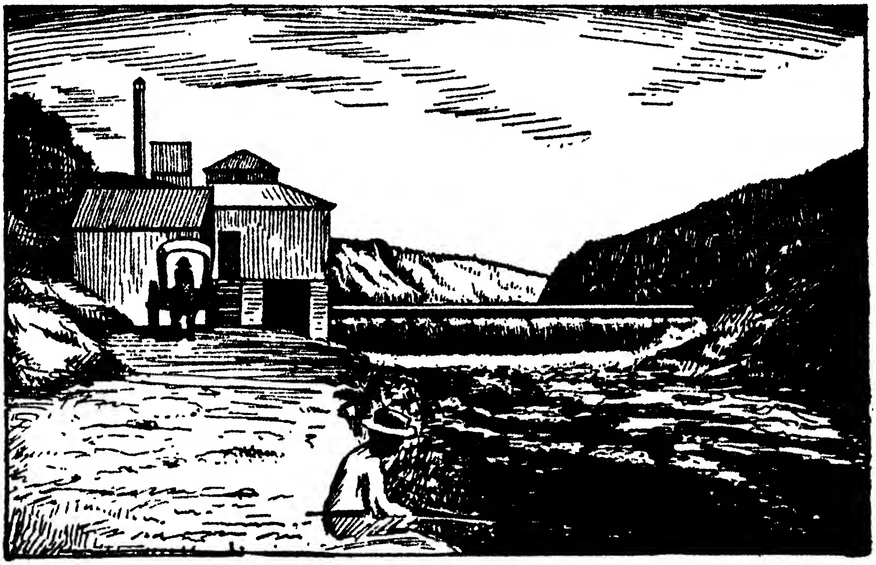


FIG. 4,735.—View illustrating the location of a station as governed by the presence of a water fall. In such cases the natural water power may be at a considerable distance from the center of gravity of the distribution system because of the saving in generation In the case of long distance transmission very high pressure may be used and a transformer step down substation be located at or near the center of gravity of the system thus considerably reducing the cost of copper for the transmission line

If the plant is to be located in a city, the matter of water supply need not generally be considered, because, as a rule, it can be obtained from the waterworks; there will then, of course, be a water tax to consider and this, if large, may warrant an effort being made to obtain the water in some other way. In any event, however, the possibility of a scarcity in the supply should be reduced to a minimum.

If the plant be located in the country, some natural source of water would

be utilized unless the place be supplied with waterworks, which is not generally the case. It is usual, however, to find a stream, lake or pond in the vicinity, but if none such be conveniently near, an artesian or other form of well must be sunk.

If abundance of water exist in the vicinity of the proposed installation, not only would the location of the plant be governed thereby, but the kind of power to be used for its operation would depend upon this. Thus, if the quantity of the water were sufficient throughout the entire year to supply the necessary power, water wheels might be installed and used in place of boilers and steam engines for driving the generators. The station

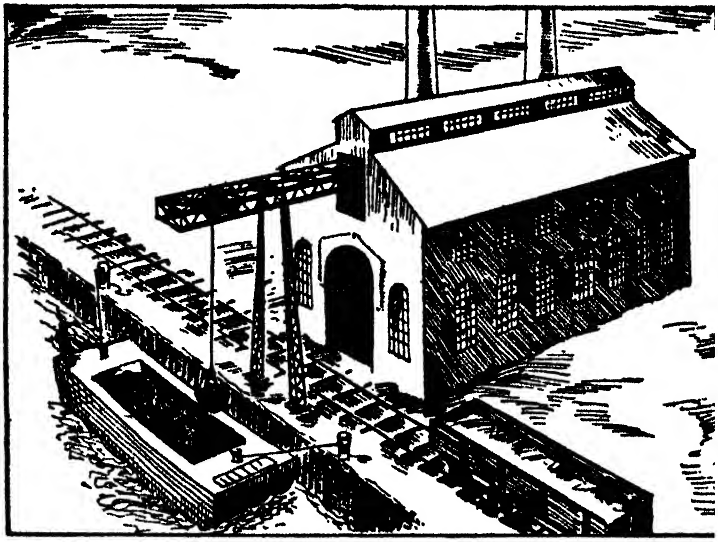


FIG. 4,736.—View of a station admirably located with respect to transportation of the coal supply *As shown*, the coal may be obtained either by boat or rail and with modern machinery for conveying the coal to the interior of the station the transportation cost is reduced to a minimum

would then, of course, be situated close to the waterfall, regardless of the center of gravity of the system.

With respect to the coal supply, the selection of a site for a power station should be such as will be convenient for transporting the coal from the supply point to the boiler room.

In this connection, an admirable location, other conditions permitting, is adjacent to a railway line or water front so that coal delivered by car or boat may be unloaded directly into the bins supplying the boilers.

If the coal be brought by train, a side or branch track will usually be found convenient, and this will usually render any carting of the fuel entirely unnecessary.

In whatever way the coal is to be supplied, the liability of a shortage due to traffic or navigation being closed at any time of the year should be well looked into, as should also the facility for the removal of ashes, before deciding upon the final location for the plant.

Choice of System.—The chief considerations in the design of a central station are economy and capacity. When the current has to be transmitted long distances for either lighting or power purposes, economy is attainable only by reducing the weight of the copper conductors. This can be accomplished only by the use of the high voltage currents obtainable from alternators.

Again, where the consumers are located within a radius of two miles from the central station, thereby requiring a transmission voltage of 550 volts or less, dynamos may be employed with greater economy.

Alternating current possesses serious disadvantages for certain important applications.

For instance, in operating electric railways and for lighting it is often necessary to transmit direct current at 500 volts a distance of five or ten miles. In such cases, the excessive drop cannot be economically reduced by increasing the sizes of the line wire, while a sufficient increase of the voltage would cause serious variations under changes of load. Hence, it is common practice to employ some form of auxiliary generator or booster, which when connected in series with the feeder, automatically maintains the required pressure in the most remote districts so long as the main generators continue to furnish the normal or working voltage.

The advantage of a direct current installation in such cases over a similar plant supplying alternating current line is the fact that a storage battery may be used in connection with the former for taking up the fluctuations of the current, thereby permitting the dynamo to run with a less variable load, and consequently at higher efficiency.

Direct current is required for certain kinds of electrolytic work, such as electro-plating, the electrical separation of metals, etc., also the charging of storage batteries for electric automobiles.

Sometimes the central station must be equipped with suitable apparatus for supplying both direct and alternating current.

Thus, it is evident that the character of a central station will be governed to a great extent by the class of services to be supplied.

An exception to this is where the entire output has to be transmitted a long distance to the point of utilization.

In such cases a copper economy demands the use of high tension alternating current, and its distribution to consumers may be made directly by means of step down transformers mounted near by or within the consumers' premises, or it may be transformed into low voltage alternating current by a conveniently located sub-station.

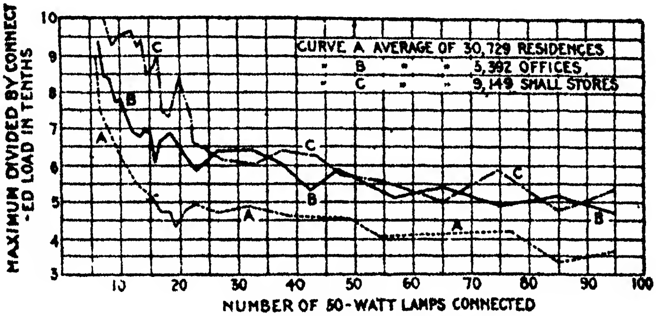


FIG. 4,737.—Diagram illustrating diversity factor. By definition *diversity factor* = *combined actual maximum demand of a group of customers divided by the sum of their individual maximum demands*. Example, a customer has fifty (50) watt lamps and, of course, the sum of the individual maximum demands of the lamps is 2.5 *kw.* watts ("connected load"). The customer's maximum demand, however, is 1.5 *kw*. Hence, the diversity factor of the customer's group of lamps is 1.5 ÷ 2.5 = .6. In the diagram the ordinates of the curves show the ratio *maximum demand to connected load* for various kinds of electric lighting service.

Where the current is to be used chiefly for lighting and there are only a few or no motors to be supplied, the choice between direct current and alternating current will depend greatly upon the size of the installation, direct current being preferable for small installations and alternating current for large installations.

If the current is to be used primarily for operating machinery, such as elevators, traveling cranes, machine tools and other devices of a similar character, which have to be operated intermittently and at varying speeds and loads, direct current is the more suitable; but if the motors performing such work can be operated continuously for many hours at a time under practically constant loads, as, for instance in the general work of a pumping station, alternating current may be employed with advantage.

*NOTE.—The *diversity factor* of a customer's group of lamps, namely, the ratio of maximum demand to connected load is usually called the *demand factor* of the customer.

Size of Plant.—Before any definite calculation can be made, or plans drawn, the engineer must determine the probable load. This is usually ascertained in terms of the number and distances of lamps that will be required, by making a thorough canvass of the city or town, or that portion for which electrical energy is to be supplied. The probable load that the station is to carry when it begins operation, the nature of this load, and the prob-

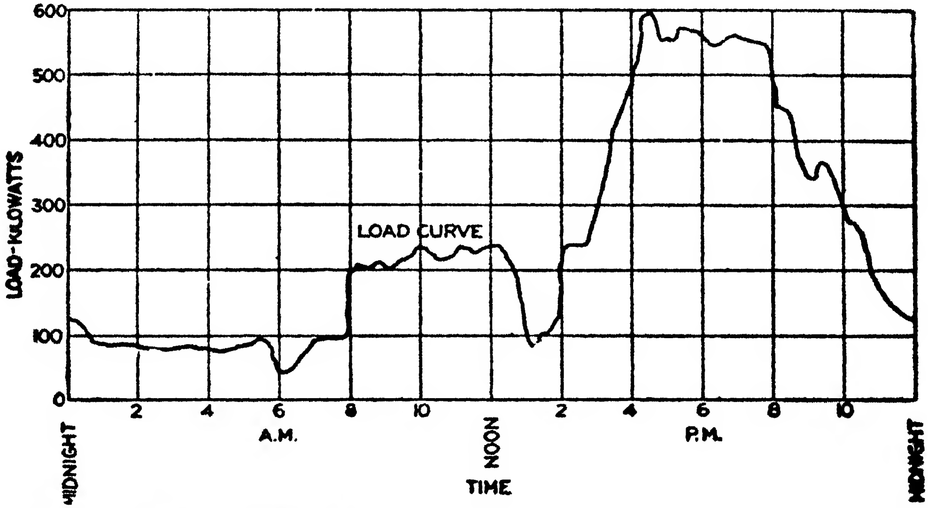


Fig. 4,738.—Load curve for one day.

able rate of increase are matters upon which the design and construction chiefly depend.

The load carried by a central station fluctuates with the time of day and also with the time of year.

A fluctuating load is best represented graphically, that is to say by means of a curve plotted on coordinate paper of which ordinates represent load values and the corresponding abscissæ time values, as in the accompanying curves.

Where electricity is supplied for power purposes to a number

of factories, the load is fairly steady, dropping, of course, during meal hours. In the case of traction, the average value of the load is fairly steady but there are momentarily violent fluctuations due to starting cars or trains.

The *peak load* is the maximum load which has to be carried by the station at any time of day or night as shown by the highest point of the load curve.

The machinery of the station evidently must be large enough

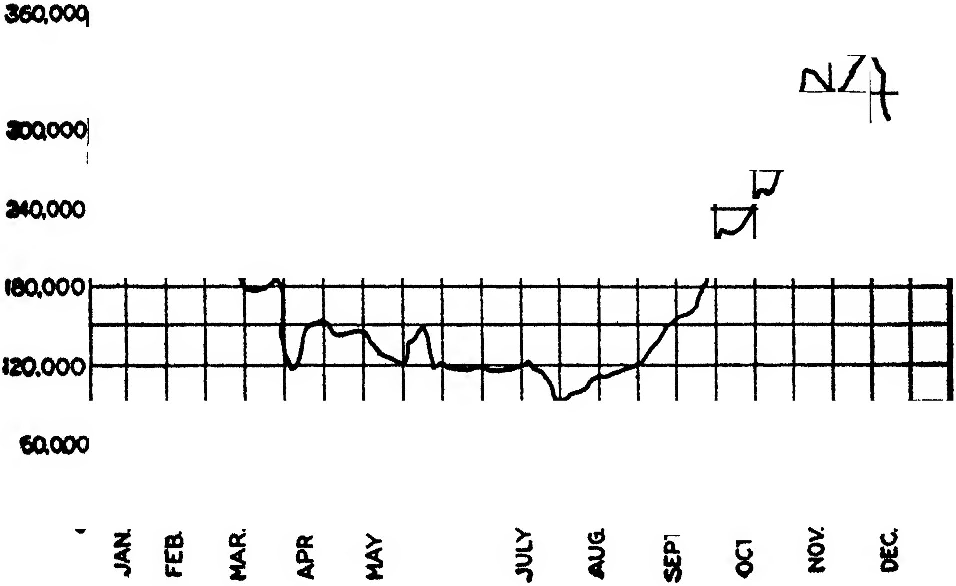


FIG. 4,739.—Load curve for one year.

to carry the peak load, and therefore considerably in excess of that required for the average demand. *The ratio of the average to the maximum load is called the* **load factor.**

There are two kinds of load factor: the annual, and the daily.

The annual load factor is obtained as a percentage by multiplying the number of units sold (per year) by 100, and dividing by the product of the maximum load and the number of hours in the year. The daily load factor is obtained by taking the figures for 24 hours instead of a year.

In addition to the machinery required to supply the peak load, there must be provided additional units for use in case of repairs or break down of some of the other units.

***Steam Power Stations**.—Boiler pressures for years have been increasing and as practiced today about 550 lbs. steam pressure, 730° steam temperature and 28.7 ins. vacuum are conservative upper limits for steam conditions in stations, yet semi-experimental plants are being constructed that exceed these limits.

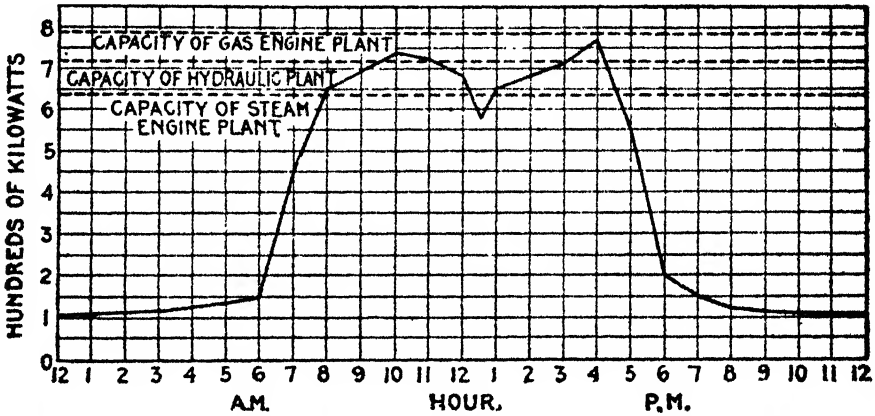


FIG. 4,740.—Load curve of plant supplying power for the operation of motors in a manufacturing district. The horizontal dotted lines show suitable power ratings. A properly designed steam plant has a large overload capacity, a hydraulic plant has a small overload capacity, and a gasoline engine plant has no overload capacity. Accordingly, the peak of the load (maximum load) may be 25 or 30 per cent in excess of the rated capacity of a steam plant, not more than 5 or 10 per cent in excess of the rated capacity of a hydraulic plant, not at all in excess of the rated capacity of a gas engine plant.

In these stations there are differences in the installations and methods used in an attempt to secure greater economy. One type utilizes steam pressure of 1,200 lbs. at a temperature of 750° in the boiler. This steam operates a turbine at the same pressure, and then is exhausted, while still dry, at a pressure of about 400 lbs. into a separately fired or live steam reheater where the temperature is raised until superheat exists. The steam then operates another turbine cylinder and exhausts to the condenser, or, in

*NOTE.—***Boilers, engines, turbines*** and steam ***auxiliaries*** have been described and their working principles explained at great length in the author's ***Engineers and Mechanics Guides*** to which the reader is referred.

some designs, two cylinders may be used in the last part of the cycle, one operating between 400 lbs. and zero pressure and the exhaust steam from this after reheating operates another cylinder under vacuum conditions. This type of operation utilizes the regenerative cycle and a large part of the theoretical gain in efficiency is obtained indirectly through the use of the reheating operation.

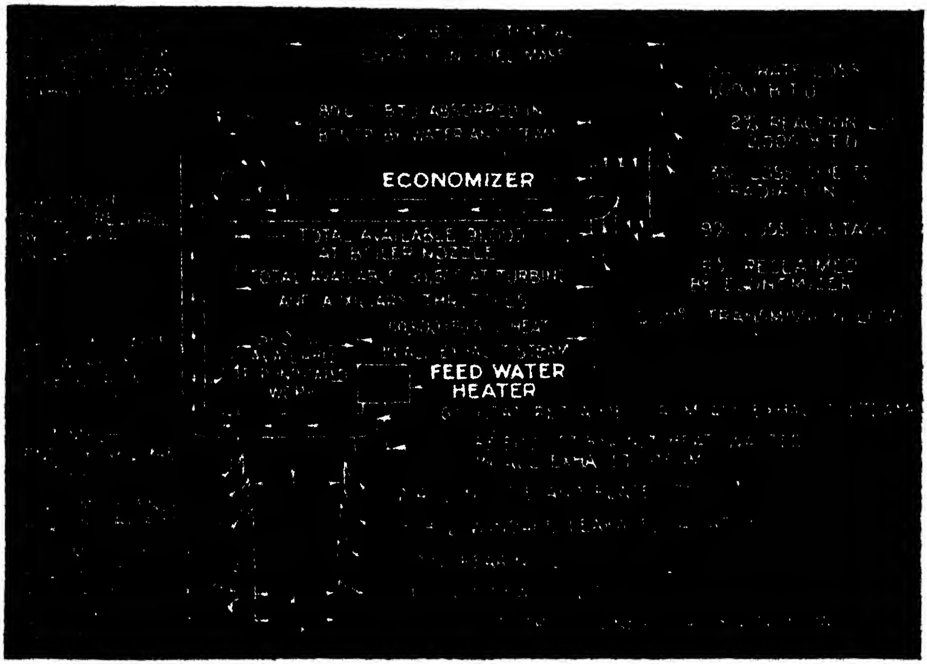


Fig. 4,741.—**Heat stream in an efficient station.** Overall thermal efficiency $= \frac{25,000}{100,000} = 25\%$. *B.t.u.* per *kw.* hour based on 14,000 *B.t.u.* coal = 0.975 lb. *B.t.u.* per *kw.* hour $= \frac{0.3411}{0.25} =$ 13.650. All energy percentages refer to the energy in the fuel.—*W. J. Wohlenberg, Yale University.*

Another type of station has been suggested which will utilize the same initial pressure and temperature and the high and low pressure turbine cylinders but not the principle of reheating.

The moisture in the steam after exhaust from the high pressure turbine is to be removed by mechanical means and the steam then used in the low pressure cylinder.

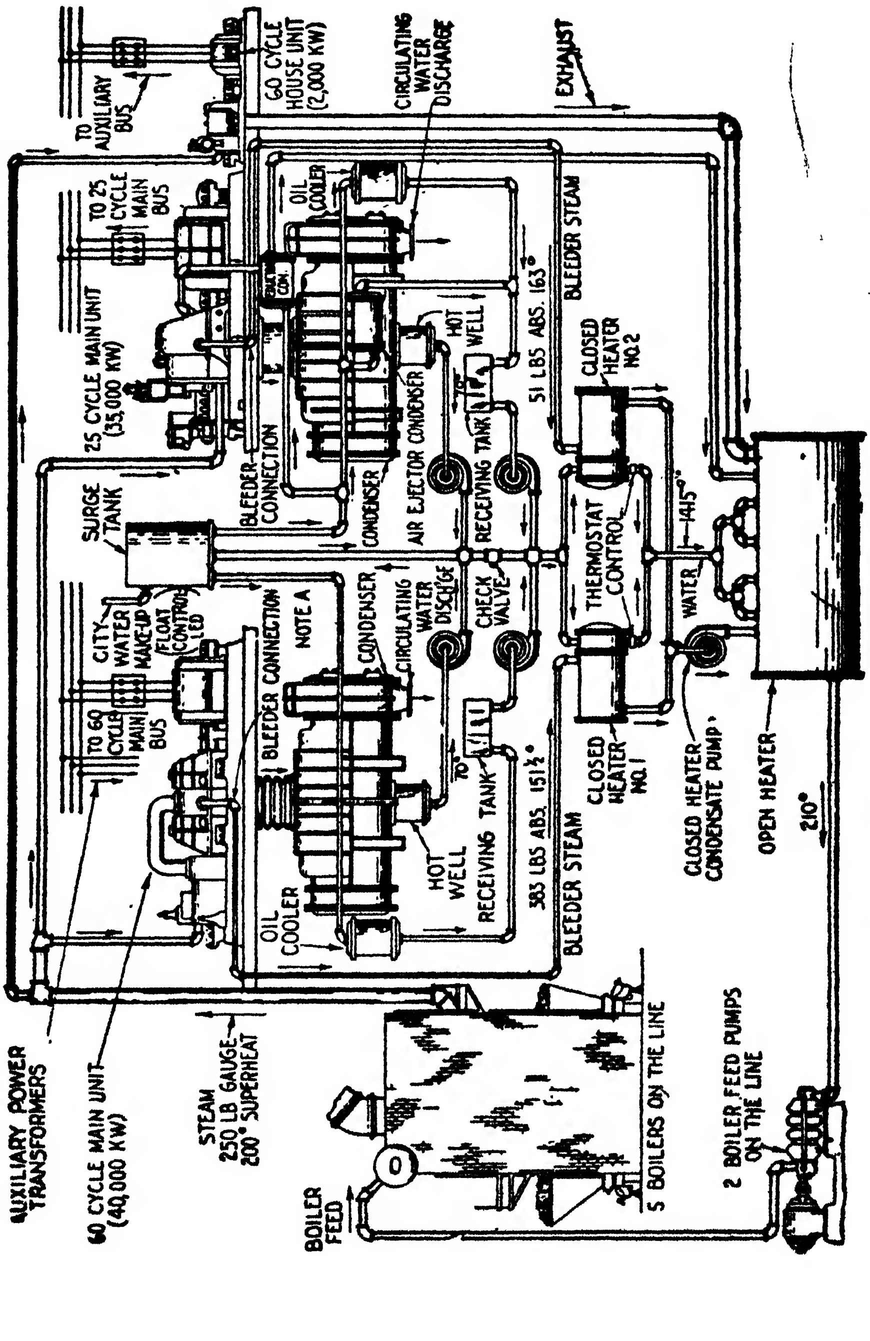


FIG. 4,742.—Layout of heat balance arrangements in Hellgate Station of the U. S. Electric Light and Power Co.

In the majority of large stations recently erected it is customary to use electric drive for major auxiliaries and to practice multi-stage bleeding of the main turbine units for heating the feed water.

If the steam be bled from the proper turbine stages, pressures and temperatures can be adjusted so that the feed water can be heated in successive stages to a degree almost equal to that of the boiler water temperature and a very efficient thermal system exists; the practical disadvantages of the bleeding system, however, as yet limit its application to two, three and four stage bleeding.

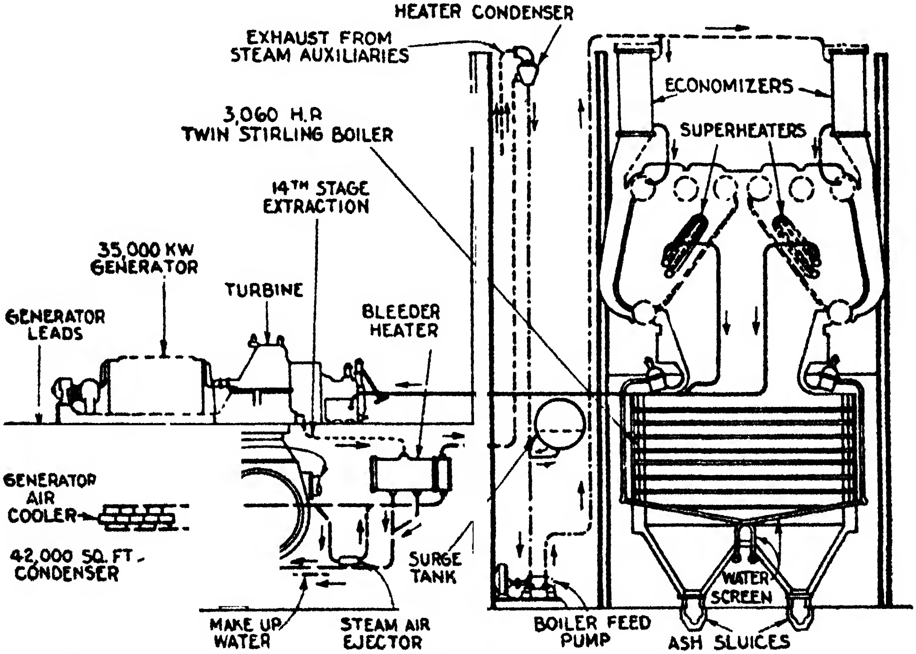


FIG. 4,743.—Steam condenser and feed water system in Avon Station of the Cleveland Electric Illuminating Co.

Electric Drive for Steam Power Plant Auxiliaries.—Practically all of the steam power plants now being designed or built, which fall in the central station class, are using steam bled from the main units for feed water heating and thereby obtain a higher plant efficiency than is possible by using the older scheme

with steam driven auxiliaries and utilizing the exhaust steam from these for heating the feed water.

This change in the heat cycle of the plants, together with the fact that extremely high steam pressure and temperatures are being used, has made the use of electric drive for auxiliary apparatus more attractive than the use of small high pressure steam turbines or reciprocating engines.

The reliability of an induction motor is considered higher than that of such steam equipment, and the maintenance of the steam turbine and high pressure steam piping is high as compared with electric drive. It is of course necessary to supply an unfailing source of electric power.

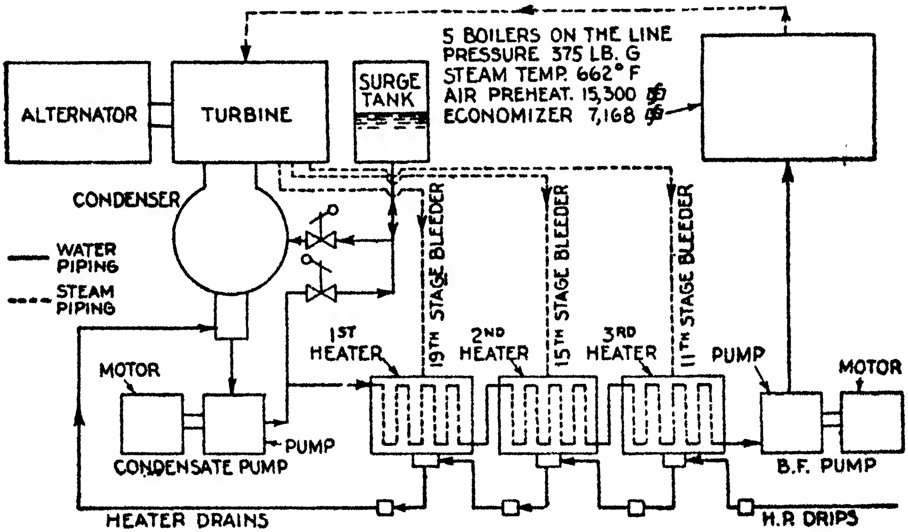


Fig. 4,744.—System of auxiliaries in the Redmond station of the Philadelphia Electric Co.

Some stations are provided with steam turbines for emergency operation of the most important auxiliaries or duplex units with a motor and turbine both connected to the same auxiliary unit. These are used principally on boiler feed and condenser pumps.

Most central stations produce *a.c.* power and this is being quite generally used for driving the auxiliaries. *A.c.* motors are simple and dependable and adjustable speed is obtained by using a wound rotor and pole changing induction motor, or brush shifting *a.c.* commutator motors, which are now available in both shunt and series types.

Where wide speed ranges are required, *d.c.* motors are sometimes necessary or desirable, and are often used for operating stokers and fans. These auxiliaries may require rather accurate speed adjustment over a wide range. This is particularly true where powdered coal or oil is used for fuel, as just the right amount of air must be supplied at all times to burn the fuel properly.

Electric drive is particularly well adapted to remote or automatic control, and many central station designers are taking advantage of these features for the auxiliaries.

Group control or centralized control of boiler room auxiliaries is quite common practice.

It is of primary importance to have motors and control such that in case of momentary voltage failure the auxiliaries will automatically restart. This is accomplished by the use of squirrel cage motors designed for full voltage starting, and by modifications in control of slip ring and commutator type motors which insure sufficient starting torque from the motors to start the auxiliaries.

The switching equipment required for auxiliary power circuits is becoming an important item in the modern central station due to the increasing amounts of power to be handled at 2,300 volts.

It is not unusual to find that switches with upward of 100,000 *kva.* rupturing capacity are required for 2,300 volt auxiliary feeder switches in the larger generating stations.

General Arrangement of Steam Electric Stations.—This should follow certain rules, whenever space is available. The first consideration is the relative arrangement of the boiler and turbine rooms. The preferable arrangement is to have one row of boilers parallel with the line of turbines, as shown in fig. 4,746, with large boilers set singly; but as the size of the turbine unit increases beyond 2,000 *kw.* the length of the boiler room usually exceeds the length of the turbine room, whence it is necessary to set the boilers in batteries.

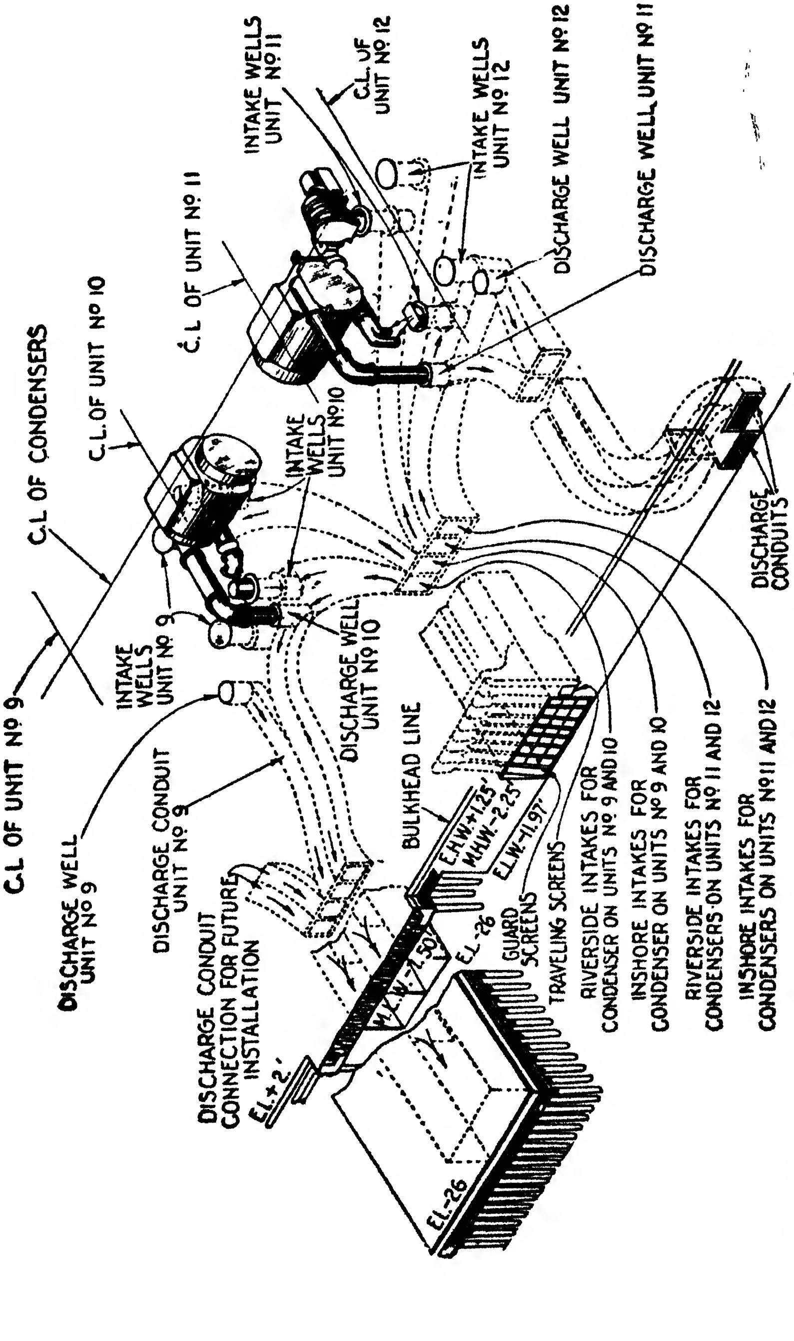


FIG. 4,745.—Circulating water system of the Richmond station of the Philadelphia Electric Co.

For turbines of 7,000 or 8,000 *kw*. capacity, the double row of boilers with central firing aisle, as illustrated in fig. 4,747, would be the next choice.

For stations of 15,000 and 20,000 *kw*. units, the boiler rooms are generally turned at right angles to the turbine room, as shown in fig. 4,748.

These arrangements follow the unit plan which is now universally recommended and which greatly simplifies the piping.

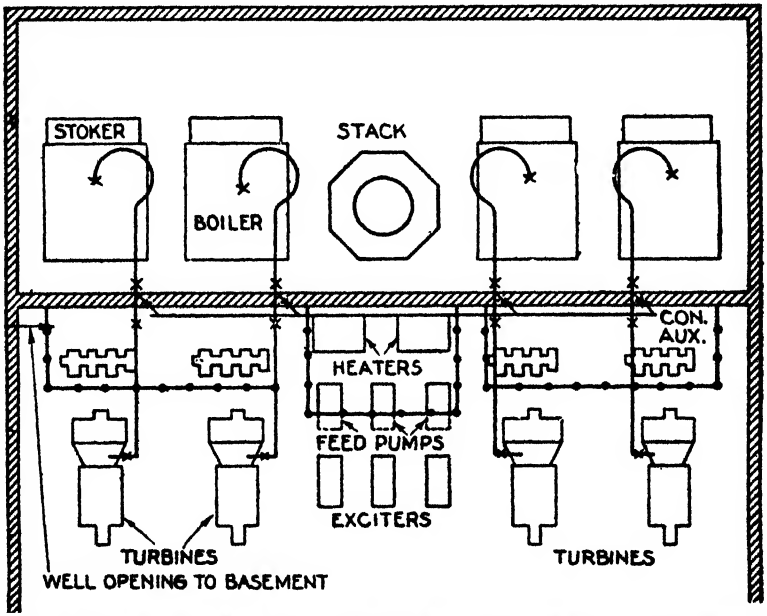


FIG. 4,746.—Station arrangement for turbine units up to about 2,000 *kw*. capacity.

Past practice provided for greater boiler reserve; but the care and attention given to proper boiler maintenance and operation that a complete complement of spare boilers suitable for the spare turbines provides perfect security.

The general arrangement of the auxiliaries are shown in the illustrations.

Steam driven auxiliaries are shown, but as pointed out in the preceding section, electric drive is the prevailing practice.

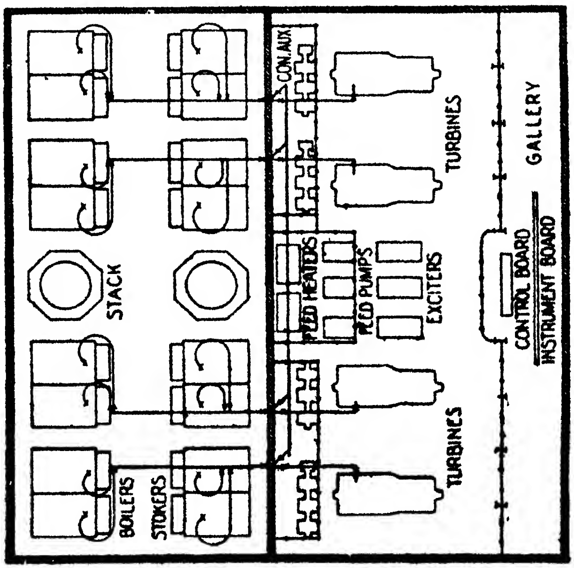


FIG. 4,747.—Arrangement for turbine up to about 8,000 *kw.* capacity.

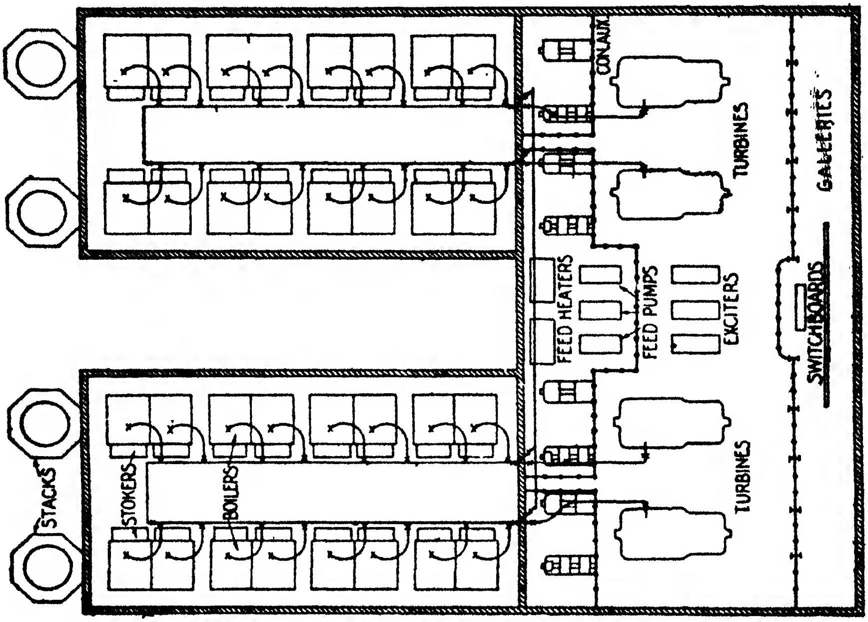
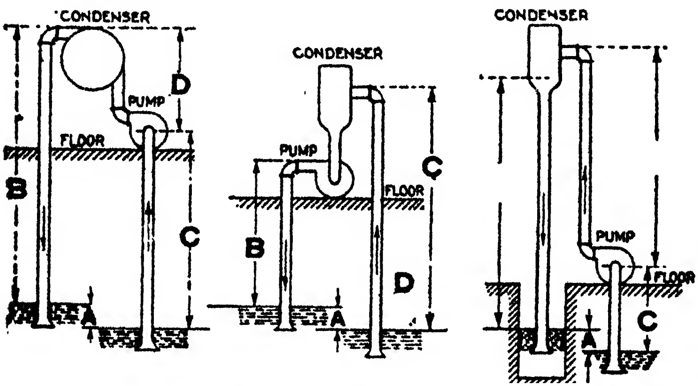


FIG. 4,748.—Arrangement commonly adopted for 15,000 and 20,000 *kw.* turbines.

Station Construction. —The construction or rearrangement of the building intended for the plant is a problem that under ordinary conditions would be solved by an architect, or at least by an architect with the assistance of an electrical or mechanical engineer, still there are many installations where the electrical engineer has been compelled to design the building.

In such instances he should be equipped with a general knowledge of the construction of buildings. It is not the purpose of the author to go into this phase of the subject.*



Figs. 4,749 to 4,751.—Pumping head for condenser pumps. Attention should be given to the amount of power consumed in driving the condenser auxiliaries, and, as the circulating pump is the greatest consumer, the pumping head as well as the volume of water should be considered. Fig. 4,749 shows the usual arrangement of the circulating pump for a surface condenser. Dimension C, should not exceed 20 feet which is about the limiting value of lifting power of the pump. The static pumping head C+D is affected by the siphon action due to the discharge, provided B, do not exceed 25 feet, as it is not safe to figure on a siphon of over 25 feet. If B, do not exceed 25 feet, then the pumping head equals A+condenser friction+pipe friction. Fig. 4,750 shows the usual arrangement of circulating pump for a low jet condenser. As stated, dimension C, should not exceed 20 feet, as some margin should be retained between the vacuum in the condenser and the static lift and pipe friction. As the distance C, is reduced, the pipe friction must be increased by throttling by a valve in this pipe line, so as to limit the amount of water which the removal pump handles. The removal pump has to pump practically against full vacuum, which, for 28 inches would be 32 feet. This results in a pumping head of 32 feet+pipe friction−B. If dimension C, must exceed 20 feet, then a pump would have to be installed in the intake line, which would not be very desirable from an operating standpoint. Such a condition could be readily met by resorting to the barometric condenser shown in Fig. 4,751 where the pumping head will be C+D+pipe friction+condenser friction. While the jet or the barometric condensers usually require less water, because of the smaller terminal difference between the outgoing water and the vacuum, they frequently involve an increase in the pumping head.

Hydro-Electric Central Stations.—The economy with which electricity can be transmitted long distances by high tension

*NOTE.—For the construction of buildings, see the author's *Builders' Guides*.

alternating currents, has led to the development of a large number of water powers in more or less remote regions.

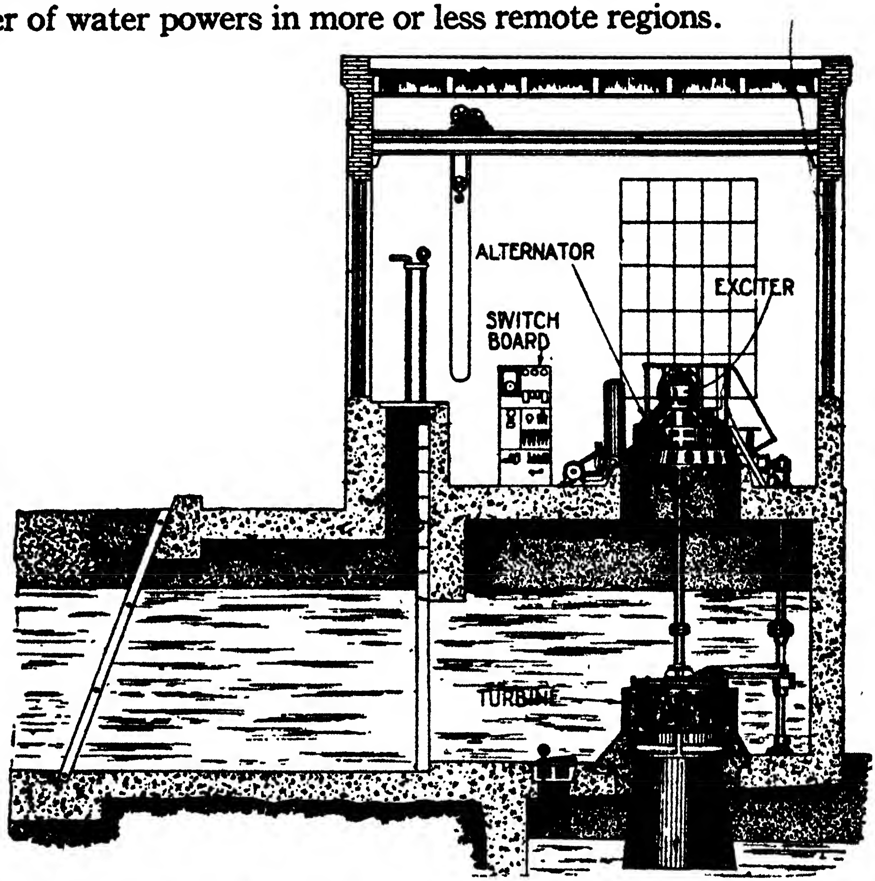


FIG. 4,752.—Section of typical hydro-electric station showing the conventional arrangement of the apparatus in a typical small hydro-electric generating station. It also shows how simple and inexpensive a type of construction can be employed in the forebay, tailrace, etc., and in the building which houses the electrical apparatus. Simple construction is worthy of emphasis because it is often a deciding economic factor in the projected development of water power sites. The same arrangement of apparatus and building, layout applies to both automatically and manually controlled stations.

This economy is possible by the facility with which alternating current can be transformed up and down. Thus at the hydro-electric plant, the current generated by the water wheel driven alternator is transformed to very high pressure and transmitted with economy a long distance to the distributing point where it is transformed down to the proper pressure for distribution.

The proper selection of a hydro-electric power house is governed by so many local considerations that a thorough study of the situation is essential in each individual case. The greater part of the cost of power production in hydraulic power houses is the fixed charges, and the initial cost of footings and foundations represents a considerable share of the total first cost.

The principal conditions determining the selection of a site are:

1. Bearing load of soil.
2. Suitable disposition of tail water.

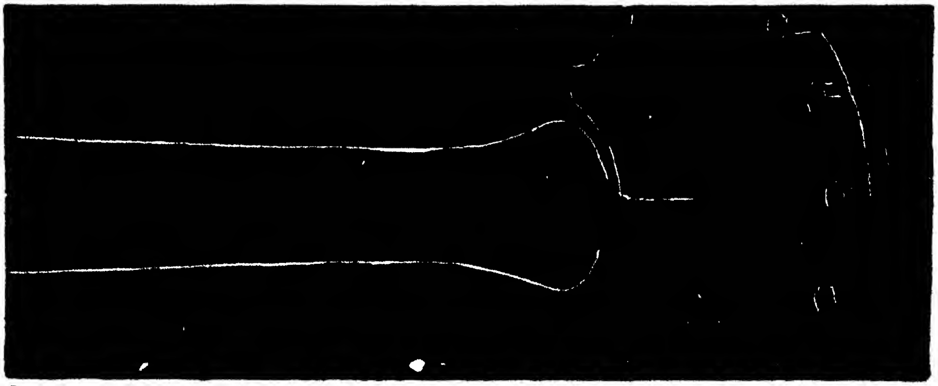
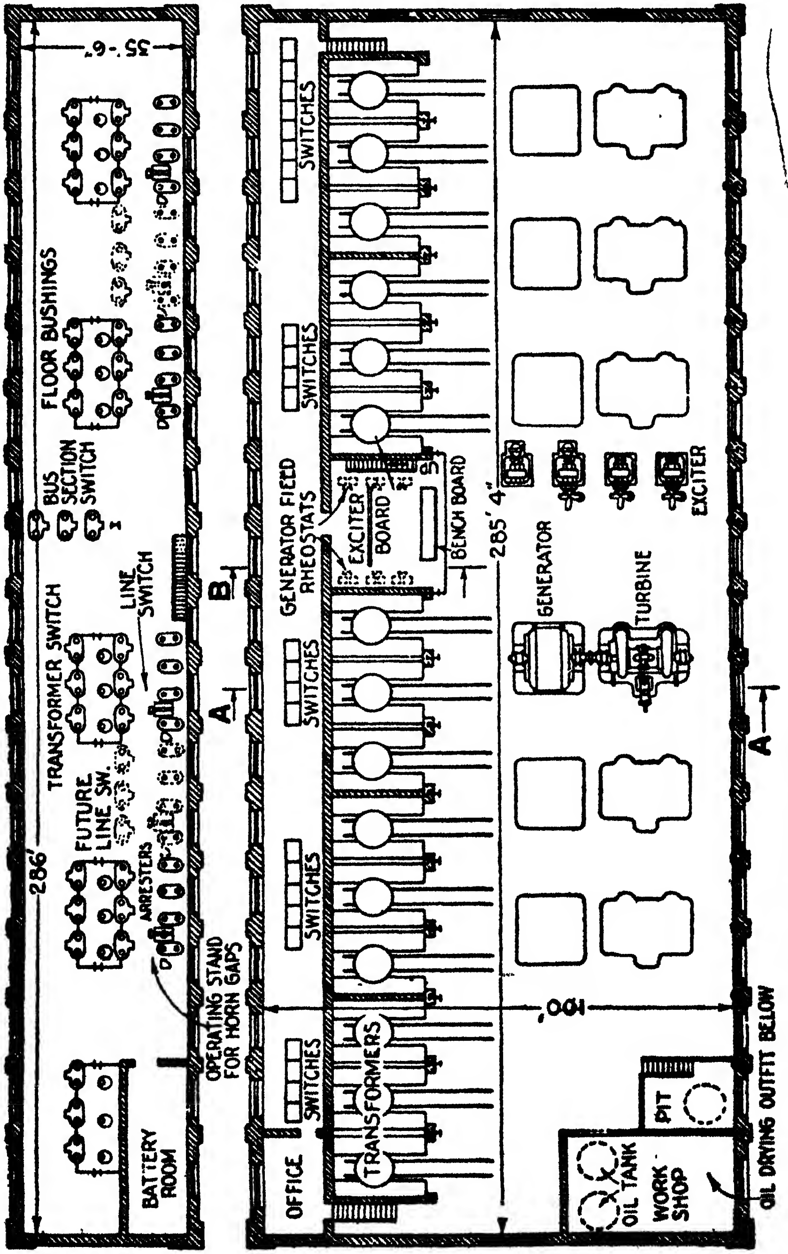


FIG. 4,753.—Water discharging from a needle nozzle due to a pressure of 169 lbs. per sq. in.

FIG. 4,754.—Photograph of a tangential water wheel equipped with Pelton buckets in operation.

NOTE.—*The rapidly increasing price of coal* is compelling the development of the smaller and more inaccessible supplies of water power and also the supplanting of old units by modern and more efficient machines. Modern electric equipment has made possible the development of much water power that would otherwise go to waste, for the power can be developed at the dam in some remote spot and consumed where most convenient.



FIGS. 4,755 and 4,756.—Hydro-electric power station.

3. Proximity to dam or head gates.
4. Possible arrangement and direction of penstocks.
5. Type of water wheel.

A water wheel or turbine is a machine in which a rotary motion is obtained by transference of the momentum of water; broadly speaking, the fluid is guided by fixed blades, attached to a casing, and impinging on other blades mounted on a drum or shaft, causing the latter to revolve.

The choice of a suitable water wheel lies between the *impulse wheel*, which is best suited for high heads, and the *turbine wheel.*

The water turbine may be of vertical or horizontal design. The *horizontal turbine* may be provided with a casing and located in the generating room, or it may be of the submerged type and located in a basin contiguous to the generating room, with the shaft extending through the dividing wall to the alternator.

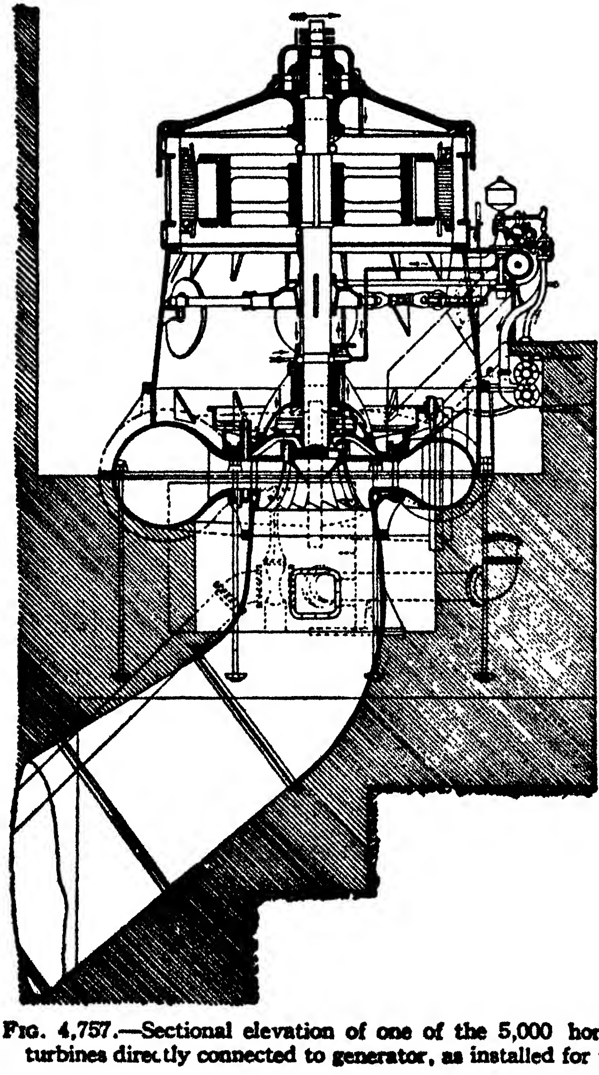
The submerged turbine is used only on very low heads, but in some cases it lends itself to a very economical and advantageous design of station.

The *vertical turbine* is particularly well adapted for large units. It takes considerably less floor space and, consequently, smaller foundation than the horizontal type. The vertical turbine necessitates the use of a step bearing; recent designs of such bearings for this purpose have proved quite satisfactory.

General Arrangement of Hydro-Electric Station.—Invariably the turbines, alternators, exciters and controlling switchboard are housed in one large room. The prime movers should be

NOTE.—*The more accessible large supplies of water power* have been largely developed, but there remains a vast quantity of easily available water power suitable for driving small and medium sized alternators. In addition to these undeveloped sites, there are many old plants consisting of horizontal shaft alternators driven by long shafts geared or belted to water wheels. These shafts have been sprung out of line, the gears have become worn and broken, the efficiency of the water wheels, originally poor, has become worse through and corrosion until, at present, some of these old installations can convert into electrical energy only half the available energy of the water. The gears and belts not only occupy much valuable space but they waste energy, are noisy, and a constant source of annoyance and expense.

arranged in a single row to simplify the penstock and tail race design, and the exciters (if not directly connected to the main units) and other auxiliary equipment common to the station should preferably be located in the center. This arrangement is shown in figs. 4,755 and 4,756.



Calculation of Water Power.—The head is found by direct measurement and the flow can be best determined by one of two generally used methods. The simplest of these is to utilize a weir to measure and compute the flow; but many streams are so large that the use of a weir would be impracticable.

It then becomes necessary to find the cross section of the stream by measurement and to ascertain the average velocity by a number of tests at various points.

FIG. 4,757.—Sectional elevation of one of the 5,000 horse power vertical Pelton-Francis turbines directly connected to generator, as installed for the Schenectady Power Co.

Weir Method.

A weir is *a sharp crested dam placed so that all the water will flow over it without restriction.*

It is known that for any given depth of water over the crest of the weir a definite quantity will flow per minute. The factors for this flow have been determined and tabulated. The accompanying table gives these figures in condensed form, which are accurate enough for any preliminary calculations. A weir should be constructed as shown in fig. 4,758.

FIG. 4,758.—Weir for measuring the water flow. Place a board across the stream at some point which will allow a pond to form above. The board should have a notch cut in it with both edges and the bottom sharply beveled toward the intake, as shown. The bottom of the notch, which is called the crest of the weir, should be perfectly level and the sides vertical. In the pond back of the weir, at a distance not less than the length of the notch, drive a stake near the bank, with its top precisely level with the crest. By means of a rule, or a graduated stake, as shown, measure the depth of water over the top of the stake, making allowance for capillary attraction of the water against the sides of the rule. For extreme accuracy, this depth may be measured to thousandths of a foot by means of a "hook gauge" familiar to all engineers.

Having ascertained the depth of water as in fig. 4,758, refer to the accompanying table from which can be calculated the amount of water flowing over the weir. There are certain proportions which must be observed in the dimensions of this notch. Its length or width should be between four and eight times the depth of water flowing over the crest of the weir.

Weir Table

Discharge in Cu. Ft. per Minute per Foot Length of Weir

Depth in In.	Discharge in Cu. Ft.	Depth in In.	Discharge in Cu. Ft.	Depth in In.	Discharge in Cu. Ft.	Depth in In.	Discharge in Cu. Ft.
¼	.54	4½	45.0	9½	130	14½	266
½	1.62	5	54.0	10	151	15	279
¾	2.94	5½	62.3	10½	163	15½	293
1	5.00	6	70.6	11	176	16	306
1½	9.36	6½	79.3	11½	188	16½	322
2	13.00	7	88.3	12	200	17	336
2½	19.20	7½	98.0	12½	212	17½	353
3	24.96	8	109.6	13	225	18	367
3½	31.20	8½	119.5	13½	240	18½	382
4	37.86	9.	129.8	14	251	19	397

The pond back of the weir should be at least 50% wider than the notch and of sufficient width and depth that the velocity of flow approach be not over one foot per second. In order to obtain these results it is advisable to make preliminary experiments.

Example.—Assume the head to be 15 ft. and that the width of the weir notch 10 ft. with water flowing over it as shown by the rule to a depth of 19 in. The table will give for 19 in. depth and one foot width 397 cu. ft. per min. Multiplying 397 cu. ft. per min. by 10, the width (in feet) of the weir in use, gives 3,970 cu. ft. per min.

Measuring Large Flows.

Many streams are so large that the use of a weir would be either impracticable or very expensive. In such a case the area of cross section of the stream is found by measuring the actual depth of the water at equal intervals between the banks, as

shown in fig. 4,759. To obtain the flow it is necessary only to find the average velocity of the water. This is done by measuring the velocity either with a current meter or with weighted floats at a number of points, as indicated by crosses, and averaging the results by adding all the velocity measurements together and dividing by the number of measurements. Then, the average velocity multiplied by the sectional area gives the flow of the stream.

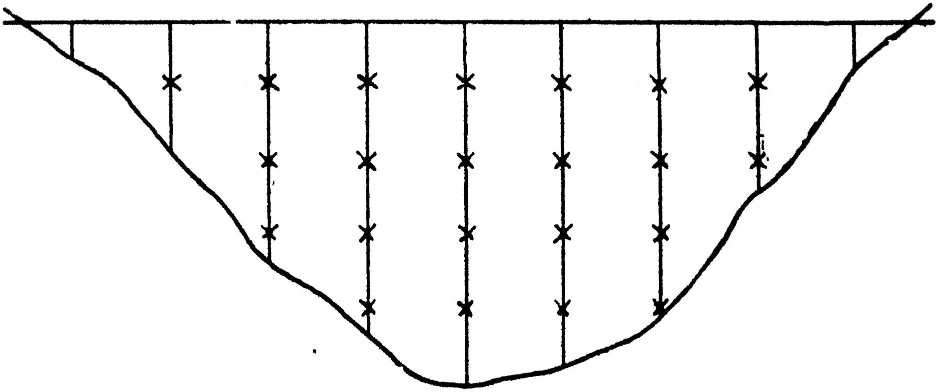


FIG. 4,759.—Method of measuring large flows.

Useful Formulæ

The horse power of a turbine is dependent on quantity of water, head and efficiency.

$$h.p. = \frac{62.4 \times H \times Q \times E}{550}$$

in which

62.4 = weight of 1 cu. ft. of water

H = head in feet

Q = flow in cu. ft. per sec.

E = percentage efficiency

(assuming that E = 80 per cent for full development)

$$h.p. = \frac{Q \times H \times E}{8.8} = \frac{Q \times H}{11}$$

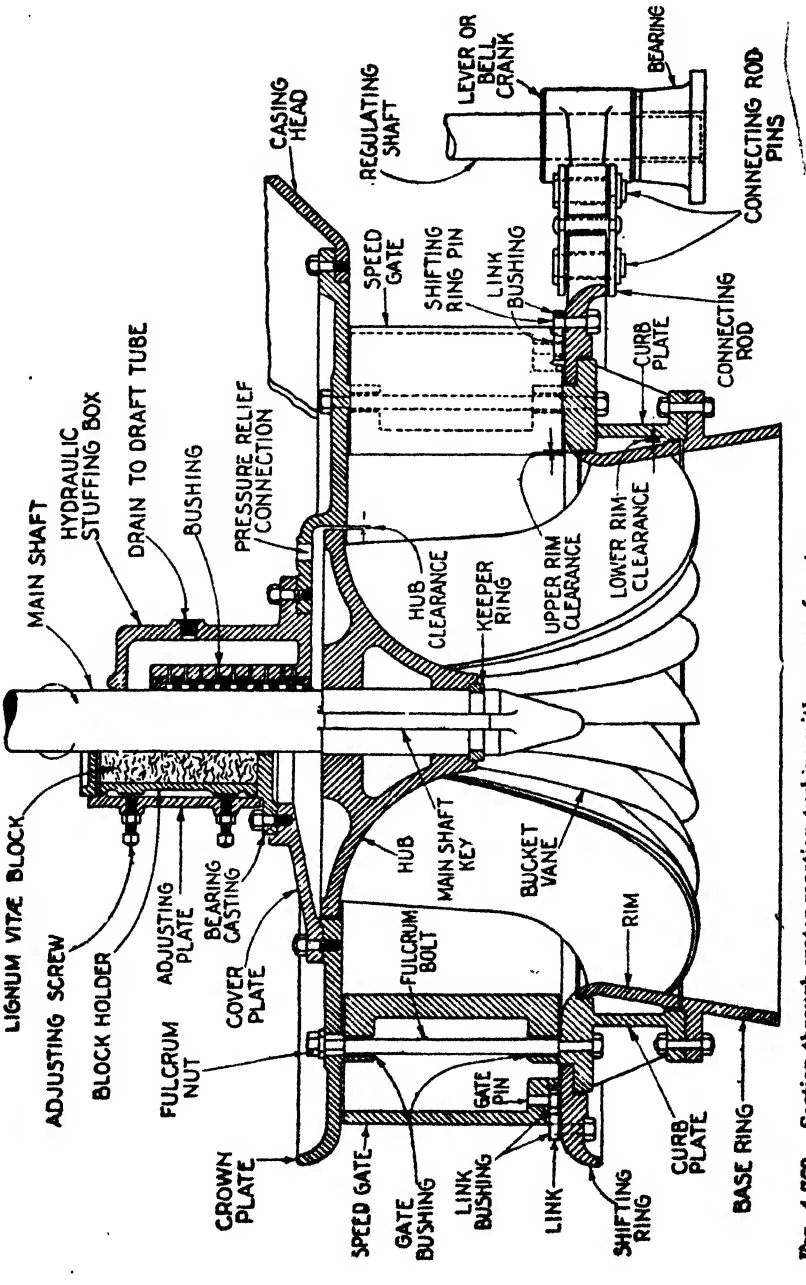


FIG. 4,760.—Section through water reaction turbine with names of parts.

the selection of an alternator is found by the formula

$$kva = \frac{H.P. \times .746 \times E \times .95}{P.F.}$$

in which P.F. = power factor, usually .8

E = alternator efficiency

.746 = constant for relation of *h.p.* to *kw.*

.95 = per cent of power at best operating point of turbine.

Approximate diameter of turbine runner:

$$D = \frac{1841.6 \times \phi \times H}{R.P.M.}$$

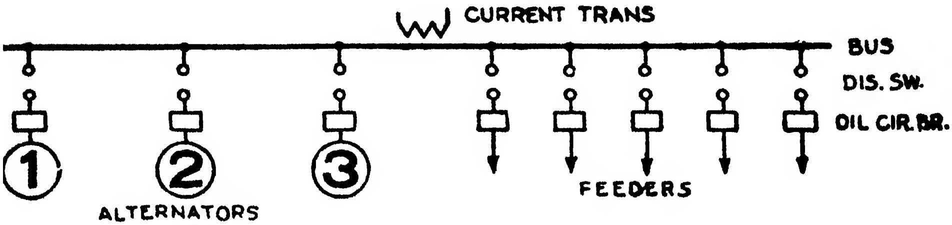


FIG. 4,761.—Single bus, single circuit breaker system

where D = diameter of runner in inches

= head in feet

R.P.M. = revolutions per minute

ϕ = .8 for low head, .7 for medium head, and .6 for high head.

Bus and Circuit Systems in Central Stations.—In this section will be considered some of the connection schemes in general use.

Fig. 4,761 shows the simplest arrangement, known as the *single bus system.*

Its use is confined to small unimportant stations where simplicity and economy are of primary importance and where possible service interruptions can be tolerated. For switching under normal conditions and for protection of apparatus in

case of failure, this simple arrangement will meet every requirement. However, there is no flexibility and a failure of any alternator circuit requires the withdrawal of the corresponding machine and breaker in service, similarly with any of the feeder circuits.

In case of insulation failure of a bus bar support, a complete shut down will result until the defect has been remedied by a rearrangement of the alternator and feeder circuit so that the feeders are taken off in between the alternators.

By use of sectionalizing disconnecting switches in the bus bars, a prolonged or complete shut down of the station may be partly guarded against.

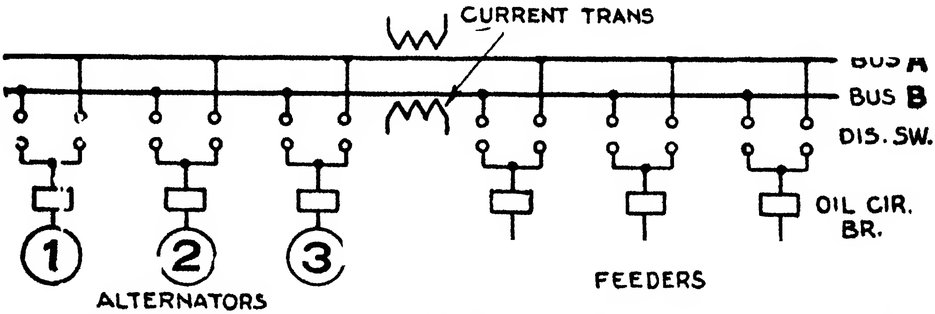


FIG. 4,762.—Double bus, single circuit breaker system. This arrangement greatly increases the chances for continuity of service over that shown in fig. 4 761. One bus bar may be used as an auxiliary only, or one may feed a lighting load while the other feeds a power load.

In the case of an insulation failure of a bus support, the total bus would be cleared of power by the operation of the oil breakers, either automatically or manually, and the defective section of the bus isolated by means of sectionalizing switches. The remainder of the station would then be put back into service.

Fig. 4,762 known as the *double bus, single breaker system* is the next step in flexibility at minimum cost.

Such an arrangement will practically eliminate the possibility of a prolonged shut down, such as might result in case of a bus failure. It also

permits maintaining service when working on either bus, such as cleaning the insulators, etc. It does not, however, eliminate the necessity of withdrawing apparatus from service in case of trouble on the corresponding circuit breaker.

The principal advantage over the previous single bus arrangement is the fact that when feeders trip out, it is possible to first test them out on the spare bus before again placing them in normal service on the main bus. Quite often a tie bus breaker shown in dotted connection, fig. 4,763, is provided to facilitate this matter of line testing or quick transferring of power

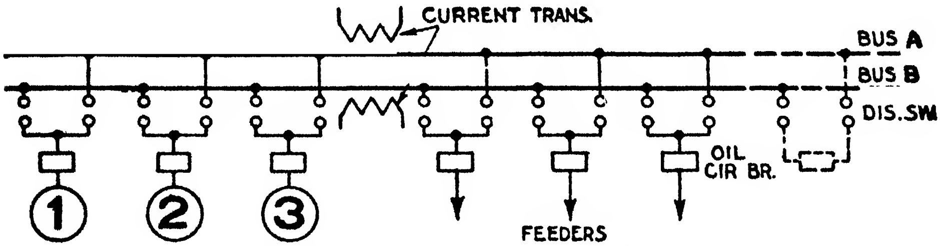


FIG. 4,763.—Double bus system with tie bus in dotted lines.

from one bus to the other. With the tie bus breaker closed, thereby energizing both sets of bus bars, the transfer of a circuit carrying power from one bus to the other can be carried out without danger of interruption to service by means of the disconnecting switches.

Fig. 4,764 shows the maximum flexibility of the scheme known as the *double bus, double breaker system.*

This has all the advantages of the double bus, single breaker system with the additional assurance against a shut down of any particular circuit, due to circuit breaker trouble. This arrangement is, of course, the most expensive which is the only criticism that could be advanced against it. For this reason, this arrangement is usually adopted only in large capacity stations where continuity of service is of prime importance and where its assurance will justify the expense.

Between the double bus, double breaker system and the single bus system, there are several other combinations which differ slightly from those described.

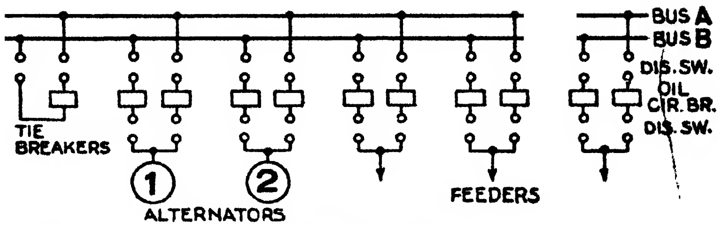


FIG. 4,764.—Double bus, double circuit breaker system.

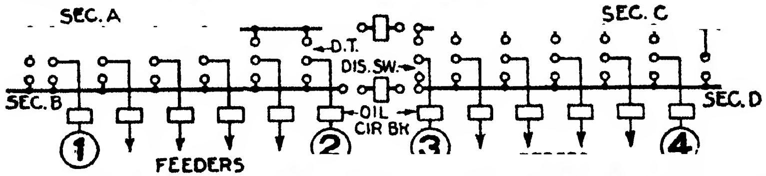
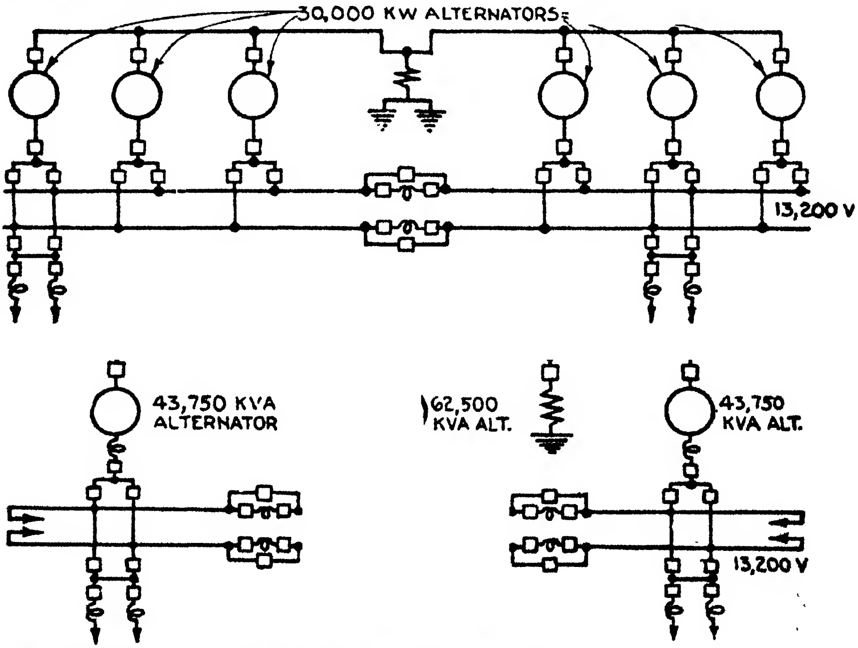


FIG. 4,765.—Ring bus system, bus sectionalized. Suitable for stations of medium size where great flexibility and maximum economy in cost are desired. This arrangement requires a very small amount of copper in the bus bars.



FIGS. 4,766 and 4,767.—Typical examples of "H" system.

The prime object, of course, of these different arrangements is to give the degree of flexibility which the local conditions seem to warrant, and at the same time keep the cost down to a minimum.

Fig. 4,765 is a modification of the double bus, single breaker system in that the two buses are tied together by means of bus

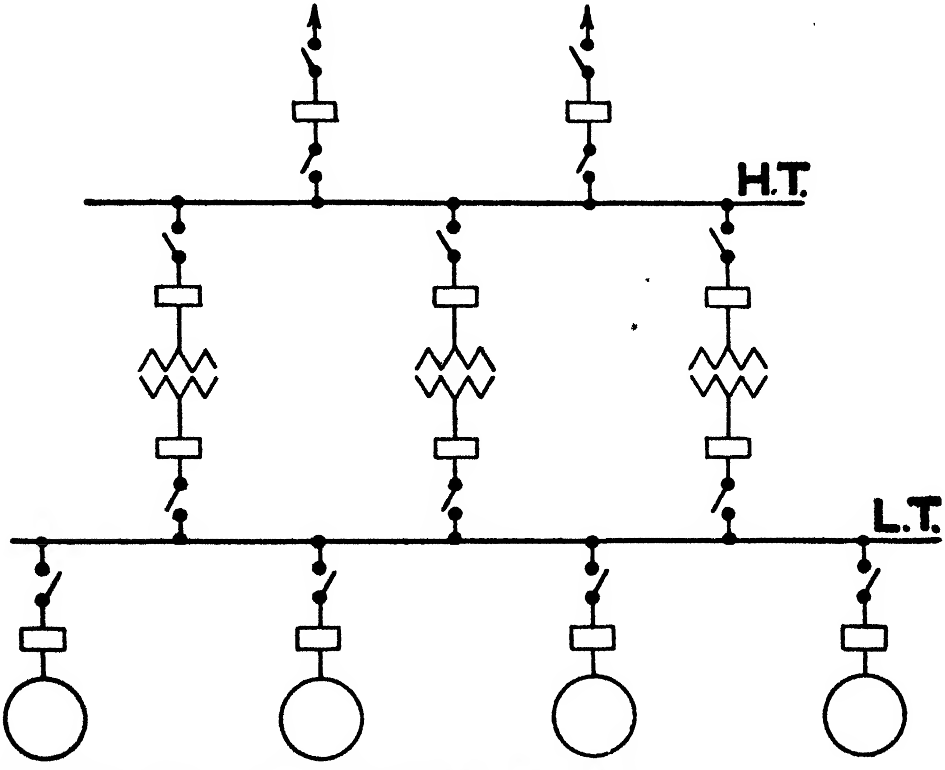


FIG. 4,768.—System using single low and high tension bus.

tie circuit breakers and disconnecting switches so as to form what is called a *ring bus*. ***For example***, large generating stations in cities such as Philadelphia, New York, etc., use a scheme known as the "H" system whereby two feeder circuits are served from a pair of selector switches to either of two buses. This typical arrangement is shown by figs. 4,766 and 4,767.

For systems distributing all or part of their power through step-up transformers, the question of bus bar connection arrangements becomes somewhat more involved.

There are many arrangements in service varying anywhere from a single low tension to a single high tension bus (as indicated in fig. 4,768), up to an elaborate arrangement using double buses, double breakers on both high and low tension circuits, as shown in fig. 4,769. If the station be at some distance from the load center, particularly hydro-electric stations, a very

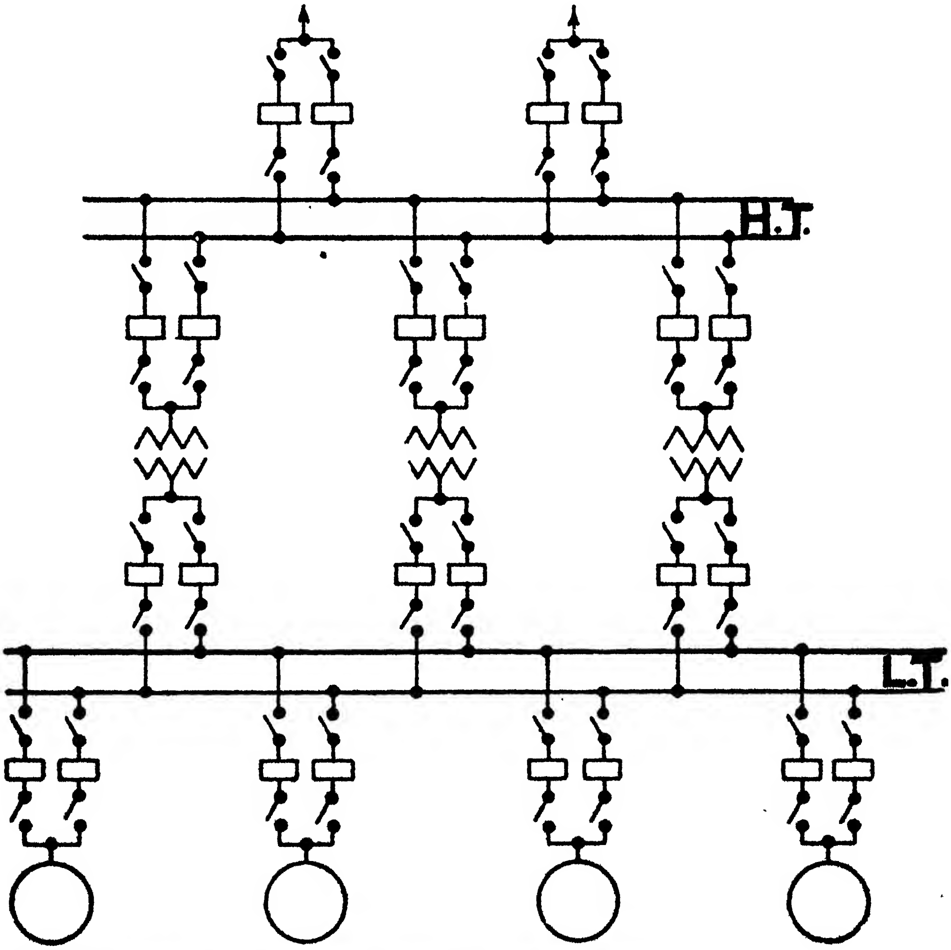


FIG. 4,769.—Bus system using double buses and double breakers.

common arrangement of buses is shown in fig. 4,770. Here the alternator and the respective step-up transformers are treated as a unit and all power is sent out over two or more lines.

Auxiliary power for the station is obtained from a low tension bus which may be connected to any one of the alternators. Normally, the alternators are not paralleled on the low tension bus. This arrangement while quite economical lacks flexibility.

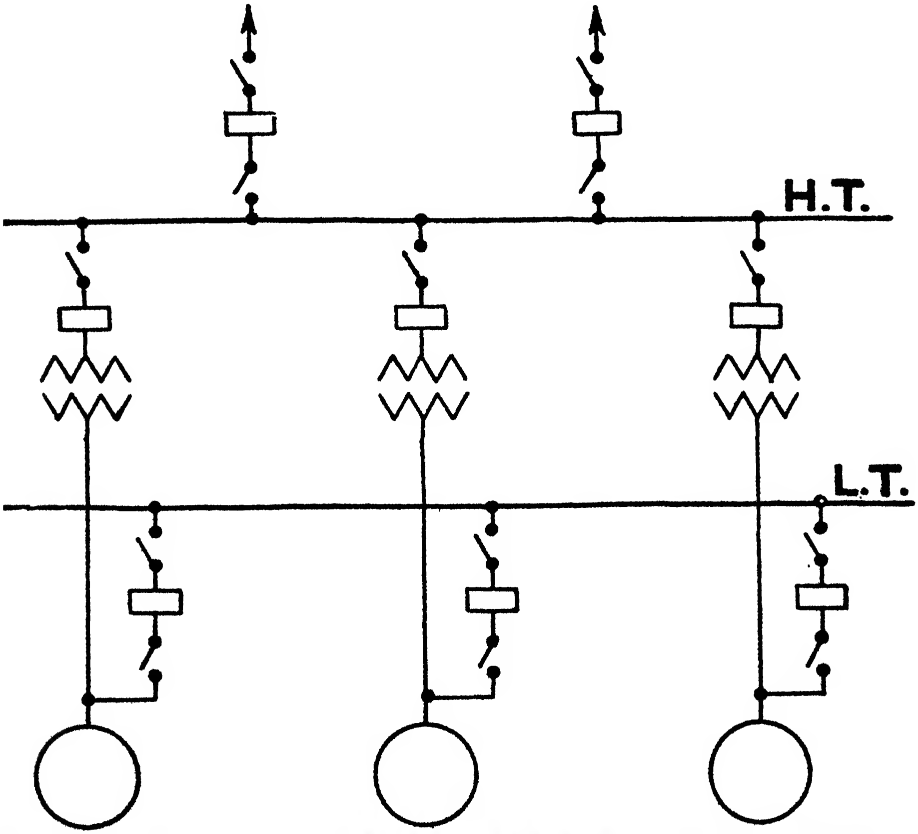


FIG. 4,770.—Common arrangement where station is at a distance from the load center.

The alternator must be used as a unit on the corresponding transformer, and the failure of either or of the conductors between them will result in a shut down of both. Further, a failure of the high tension bus will result in a complete shut down of the plant until such time as repairs can be made.

Fig. 4,771 shows a method of high tension connection which permits of certain flexibility and treats the transformer bank as part of the transmission line rather than as a unit with the alternator.

In other words, the transformer capacity is chosen with respect to the transmission line capacity. This arrangement shows three high tension

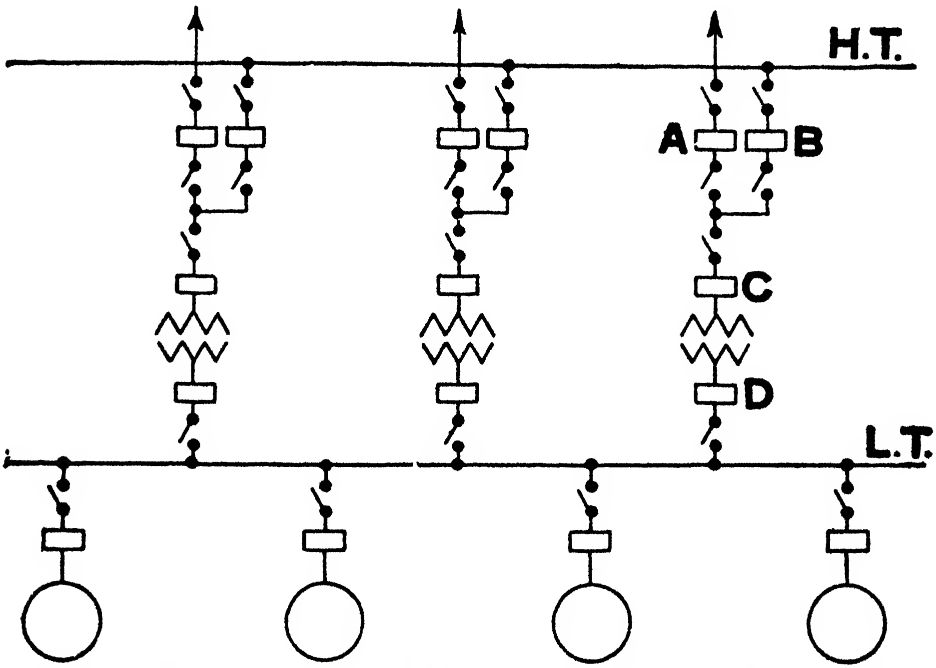


FIG. 4,771.—System in which transformers are treated as a part of the transmission line.

breakers per group and often to reduce cost, the two oil breakers, marked A, and B, are replaced by three pole air break disconnecting switches manually or electrically operated. If this substitution be made, then breaker C, operates both as a line breaker and as a transformer breaker. In fact, very often the low tension breaker D, would be used to trip out the circuit as the transformer would be considered as part of the line. The advantage of this arrangement, of course, is that when operating on the low tension side, the magnitude of voltage surges resulting from high tension switching is reduced to a minimum.

Some of the disadvantages of such an arrangement are that this scheme does not work out well in the network system, neither does it prove very

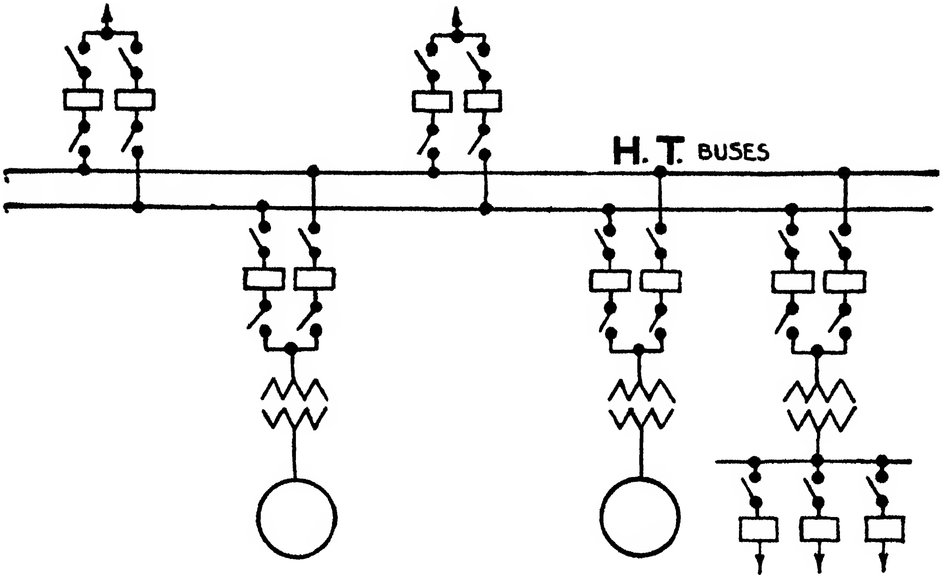


FIG. 4,772.—Bus system for large steam stations where power is fed into a H. T. network.

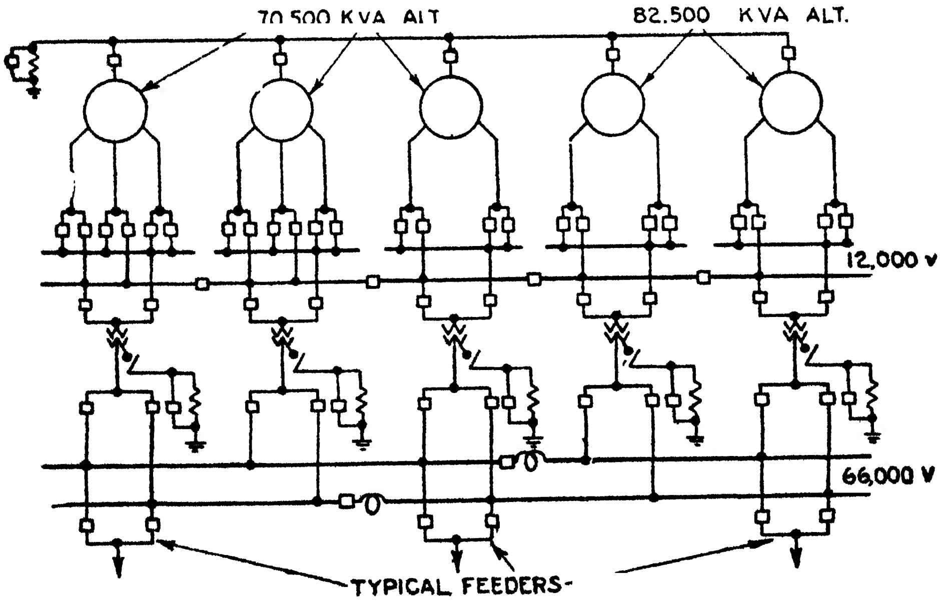


FIG. 4,773.—Bus system where all power is delivered to a H. T. bus.

economical where generating stations supply widely separated loads. This is especially true where the transformers must be of different capacity to meet the load requirements.

The particular application of such a switching arrangement seems to lie with a station where power is to be transmitted over a number of lines to a single substation. In such an event, the line and transformer banks are identical and if the line be lost, the corresponding transformer cannot be used. Consequently, in such cases, this scheme forms an effective and economical arrangement.

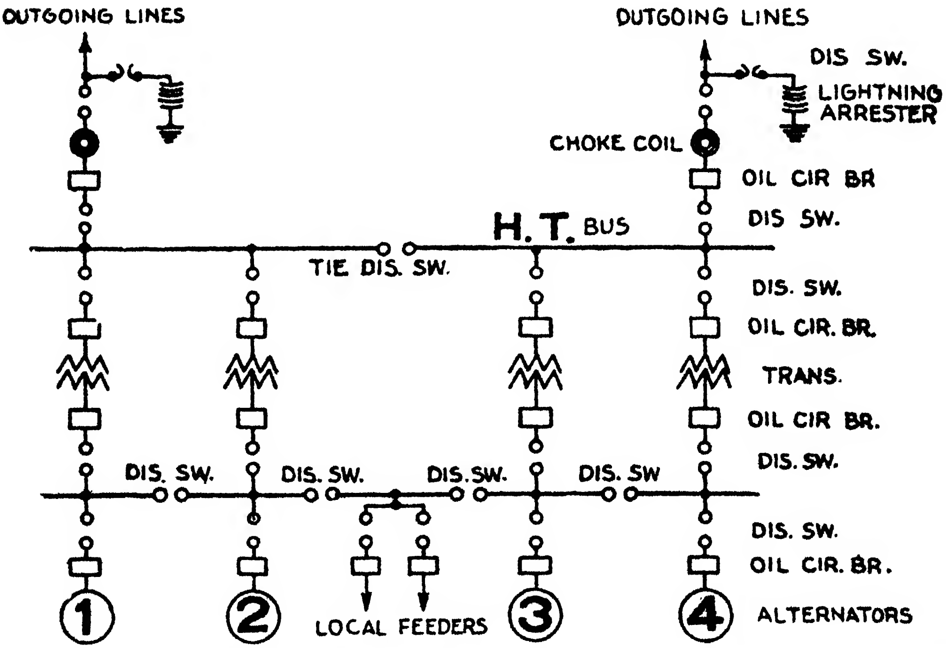


FIG. 4,774.—Single sectionalized bus system. This system gives great flexibility of operation with minimum cost and is suitable for medium sized plants. Dependence is placed on single circuit breakers. The station may be operated in separate independent halves, local feeders being fed from either half.

Fig. 4,772, shows another arrangement for large steam stations where all power is fed into a high tension net work distributed over considerable area.

This station is a so-called *base load* plant. With this arrangement, each alternator and step up transformer is treated as a unit with no switching

devices between them. The high tension bus is a straight double bus, double breaker arrangement, affording a maximum amount of flexibility. The power for station auxiliary is obtained from a high tension step down transformer bank.

Fig. 4,773, shows another station load plant where all power is delivered to a high tension bus.

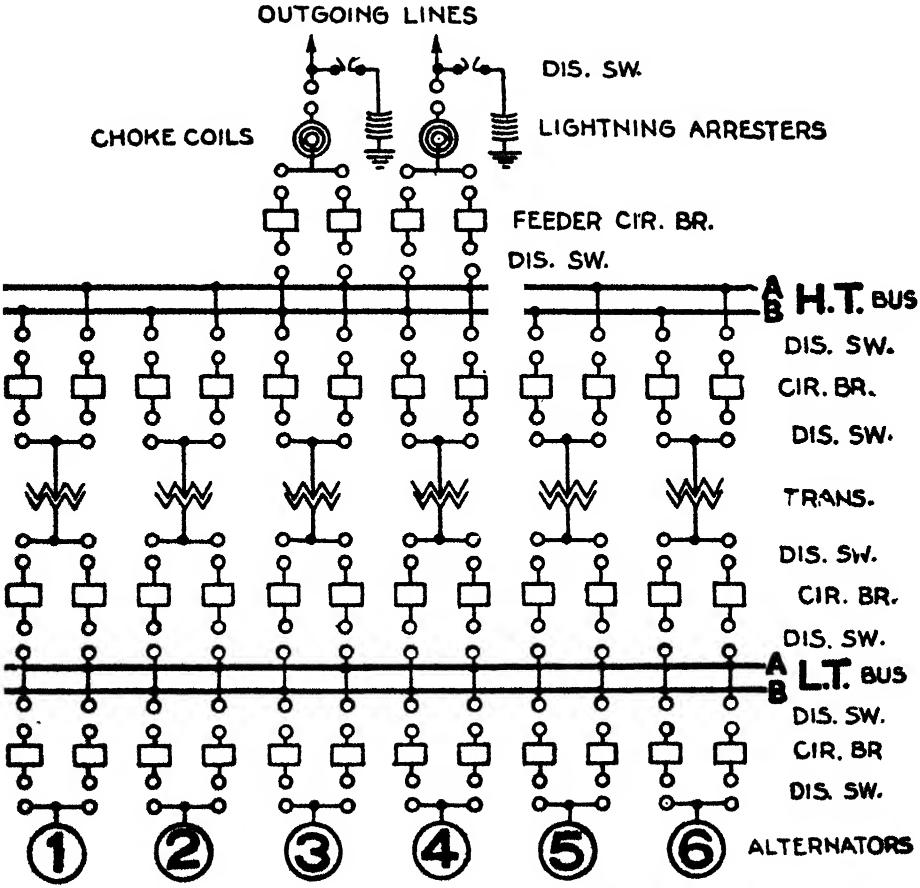


FIG. 4,775.—Double bus, double circuit breaker system. This arrangement permits the use of any or all of the alternators, without regard to which of the transformers may be in operation. It is particularly suitable where the station output is taken over but two or three transmission lines to the same destination.

In this case, the transformer banks are of exceptionally large size and the alternators are in two or three units, the steam end consisting of one high pressure and one or two low pressure turbines. A maximum amount of flexibility is to be had as double buses are provided in both high and low tension.

Figs. 4,774 to 4,777, illustrate some of the more important and commonly used arrangements of main circuits by some of the more prominent central stations in this country.

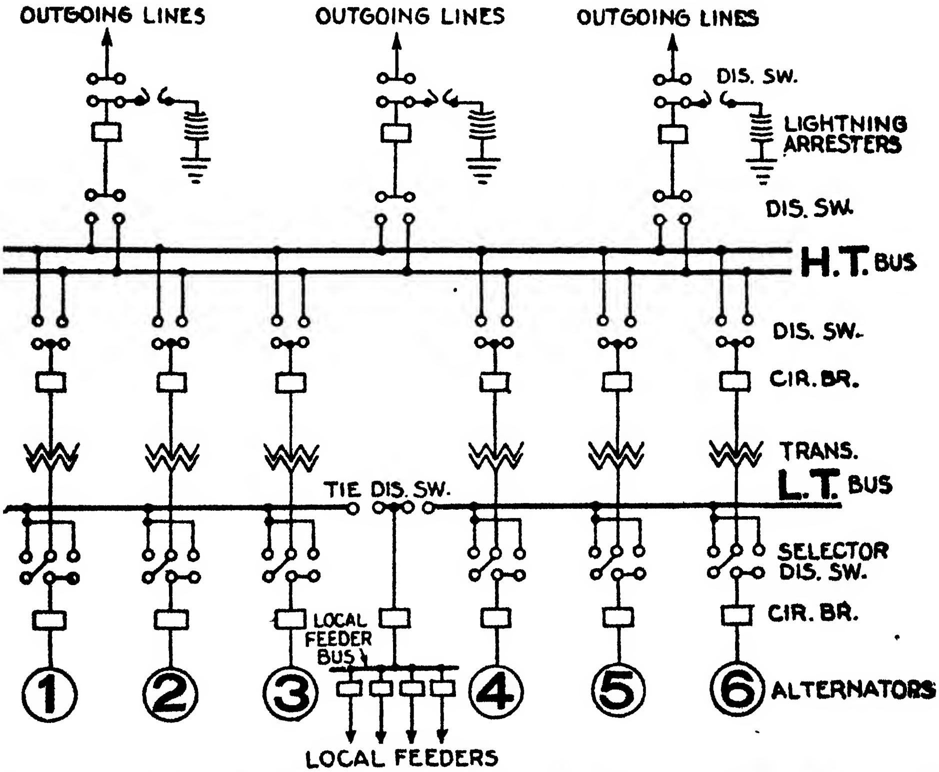


FIG. 4,776.—Single low tension, double high tension bus, single circuit breaker scheme. Low tension disconnecting switches permit the connection of an alternator direct to a transformer (with or without connection to bus bar) connection of alternator to bus bar with transformer dead or connection of transformer to bus bar with alternator dead. All apparatus may be in service while the load is removed from either section of either bus bar for repairs or additions.

TEST QUESTIONS

1. *What is understood by the term "power station"?*
2. *Give a classification of power stations.*
3. *How is the location of a central station determined?*

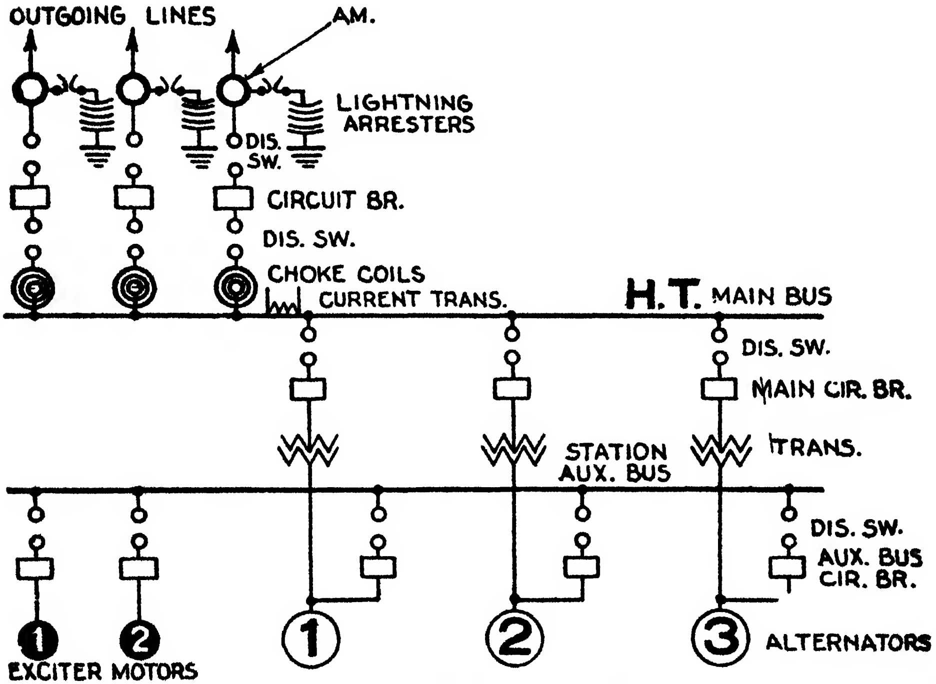


FIG. 4,777.—Single high tension bus scheme. The alternator and transformer are treated as a unit and all low tension switching is thereby omitted. The station auxiliaries are fed from any alternator or transformer circuit by means of the auxiliary bus.

4. *Define the term center of gravity as applied to distribution systems.*
5. *What factors enter into the source of location of a central station?*
6. *Why is the matter of water supply important?*

7. *What are the chief considerations in the design of a central station?*
8. *Define the terms "diversity factor" and "demand factor."*
9. *Explain in detail how the size of a central station is determined.*
10. *What is the load factor?*
11. *What boiler pressure, super-heat and vacuum are commonly used in central stations?*
12. *What kind of drive is used for the major auxiliaries?*
13. *What is the comparison between electric and steam driven auxiliaries?*
14. *Draw a sketch showing general arrangement of a steam electric station.*
15. *Describe a hydro-electric station.*
16. *Name two types of turbine used in hydro-electric stations.*
17. *What is the difference between an impulse and a re action wheel?*
18. *What is a weir?*
19. *Explain the weir method of measuring water flow.*
20. *Draw a sketch showing construction of a weir.*
21. *How is the velocity of water flow measured?*
22. *Give formula for horse power of water turbine.*
33. *Give the various bus and circuit systems in central stations.*

CHAPTER 90

Sub-Stations

By definition a sub-station is a building provided with apparatus for changing high pressure alternating current received from the central station into direct current of the requisite pressure, to meet the service requirements. In the case of a railway system of considerable length where traffic is heavy, sub-stations are provided at intervals along the line, each receiving high pressure current from one large central station and converting it into moderate pressure direct current for their districts.

The selection of apparatus and general arrangement of a sub-station depends upon the character of the work and method of converting or otherwise altering the current supplied from the central station.

There are several general classes of sub-station:

1. Manually operated;
2. Semi-automatic;
3. Automatic;
4. Portable;
5. Supervisory controlled.

In general the building for a sub-station should be substantial, convenient to install or replace the heavy machines, and the layout arranged so that the apparatus can be readily operated by those in attendance.

An overhead traveling crane is the most convenient method of handling the heavy machinery, and is frequently used in large sub-stations.

Fig. 4,779 shows a plan and fig. 4,780, an elevation for a small sub station containing two rotary converters and two banks of three single phase static transformers operating on a three phase system at 11,000 or 13,200 volts, together with the auxiliary apparatus.

In the case of three phase installations with separate trans-

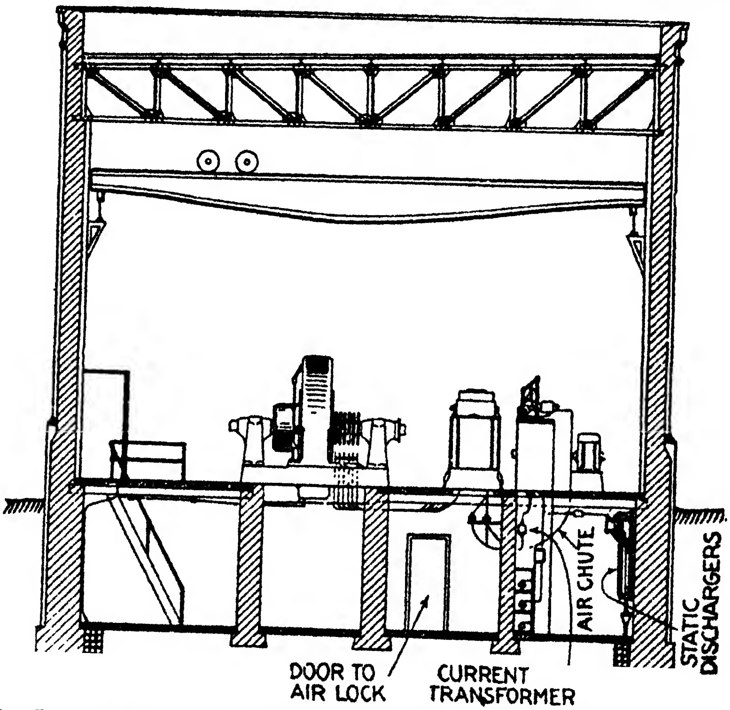


FIG. 4,778.—Plan of sub-station with air blast transformers and motor operated oil switches and underground 11,000 or 13,200 volt high tension lines.

formers as compared with combined transformers, repairs are more readily made.

The three phase units have the advantage of low first cost.

Sub-station transformers produce considerable heat, due to the hysteresis and eddy currents, and it is necessary to get rid of it.

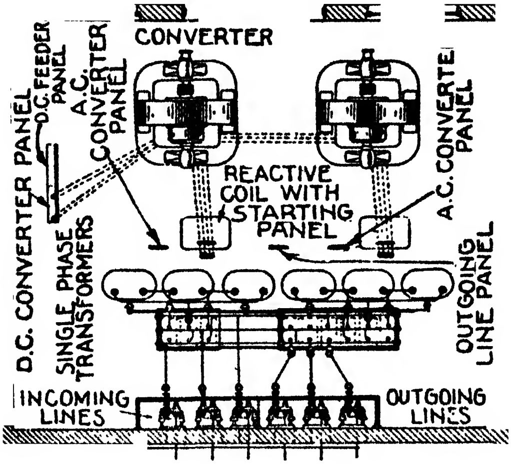


FIG. 4,779.—Plan of small sub-station with single phase oil insulated self-cooling transformers and hand operated oil switches 11,000 or 13,200 volts, overhead high tension lines.

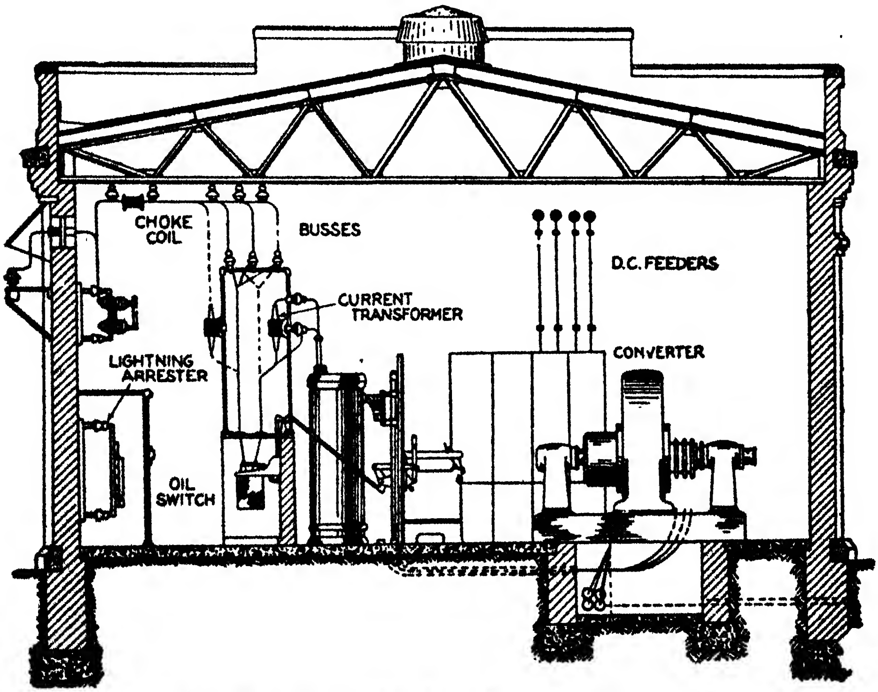


FIG. 4,780.—Elevation of small sub-station, as shown in plan in fig. 4,779.

Small transformers radiate the heat from the shell and the medium sizes have corrugated shells which increase the surface and provide more rapid radiation.

Automatic Sub-Stations.—In order to eliminate the uncertainty and expense of manual operation, unattended or automatic sub-stations have been introduced. This type of sub-station is provided with an assemblage of contactors, relays and other devices especially adapted to automatic control service.

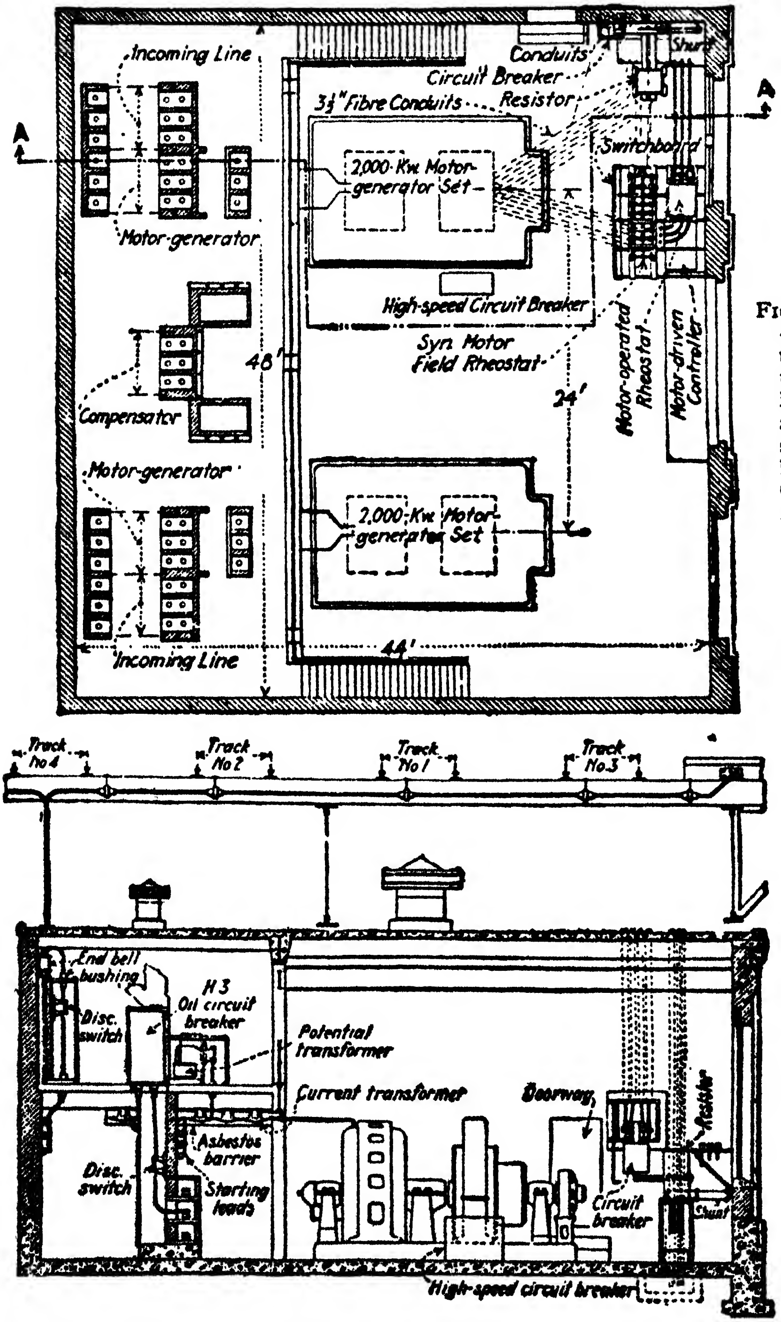
This equipment together with the motor driven master controller performs the usual functions of starting, shutting down and fully protecting the sub-station at all times, entirely independent of manual supervision.

The automatic station is usually started by a load demand on that part of the system within its particular district.

This is accomplished by a voltage relay, actuated from the trolley.

The stopping indication is given by the operation of an underload relay when the load diminishes to an uneconomical point. Starting and stopping of the station may also be accomplished by means of one of several remote control systems or by a time switch.

The sequence of the various operations is determined by the motor driven master switch which was originally developed from the platform type drum controller. The fingers and segments of this switch make and break circuits, actuating contactors and relays which act directly on the machine circuits. This type of control, in addition to insuring a fixed and correct sequence of operation, also eliminates a large number of interlocks.



FIGS. 4,781 and 4,782.—Plan and transverse section of General Electric 4,000 kw. automatic sub-station installed by N. Y. C. R.R. Co. at 110th St., N. Y. City.

As a concrete illustration, assuming a 600 volt, normal trolley pressure the automatic equipment starts the synchronous converter or motor generator when the voltage falls for instance, to 540 volts or below.

This reduction in trolley voltage is occasioned by the heavy current demand of a car just entering the zone fed by this station. The voltage relay acts, due to the reduction in voltage, and after a suitable time delay, to avoid starts due to current demands of short duration, actuates the

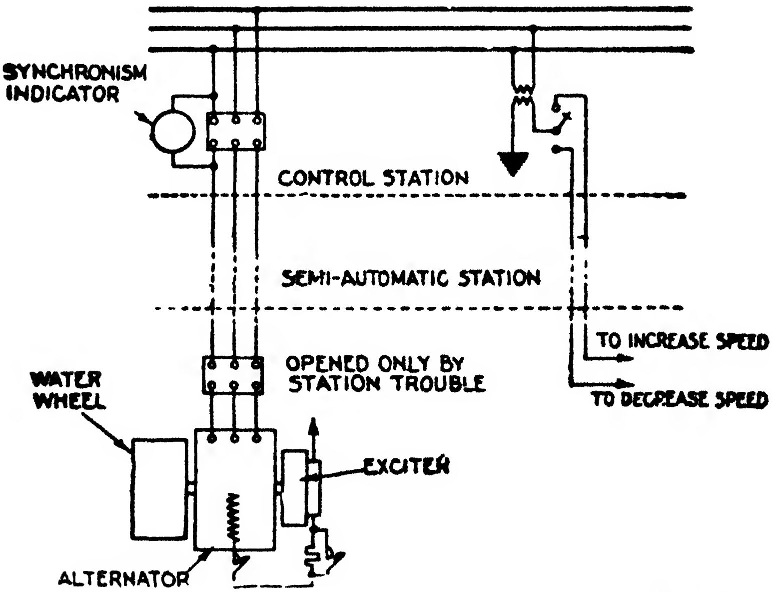


FIG. 4,783.—Control system requiring pilot wires for a remotely controlled automatic station. In the diagram a semi-automatic plant is controlled from some other station by means of a three phase power line and two additional conductors; for controlling the water wheel gate opening. The operator first closes the control switch, which causes the water wheel gate to open, thus starting the alternator. The field of the alternator is connected to the armature of the direct connected or belted exciter by the closing of the contactor in the main field circuit, and the alternator builds up the voltage as the speed increases. The operator, who has a synchronism indicator across the oil circuit breaker in the hand controlled station, adjusts the speed and synchronizes the alternator as if it were a machine in the same plant. After the alternator is synchronized, the load, which is under the operator's control, may be adjusted to any desired amount. In order to have a lower value of excitation for synchronizing than that required under full load operation, resistance is inserted in the alternator field circuit. This resistance is automatically short circuited by a contactor when the two stations are connected.

master switch. This energizes in proper sequence the operating coils of the *a.c.* starting field, and running contactors.

As soon as the machine reaches normal voltage, the *d.c.* line contactor is closed and the master switch stops. The sub-station then continues to furnish normal trolley voltage until the current demand falls below some predetermined value. This occurs, of course, when the car or locomotive, which has been taking current, passes out of the section fed from this particular station.

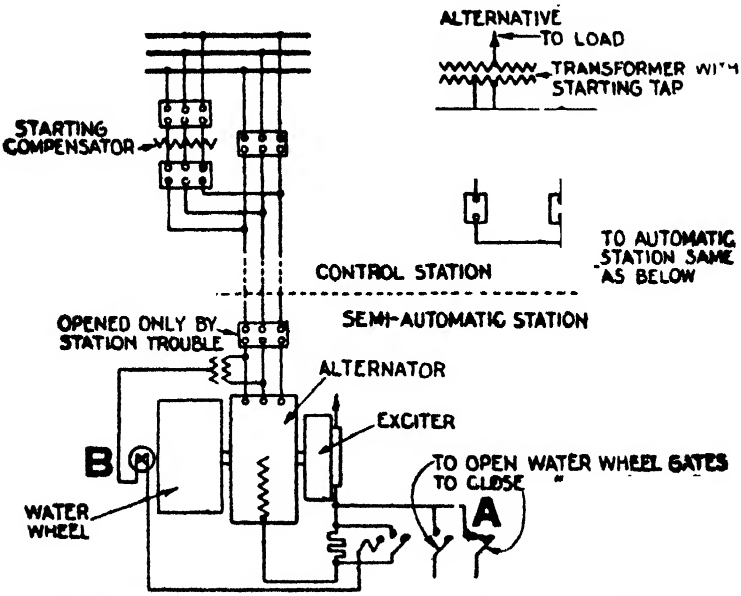


FIG. 4,784.—Control system which does not require pilot wires for a remotely controlled automatic station. The operator starts the station by impressing fractional voltage on the line. The fractional voltage may be obtained either from a starting compensator or from taps on transformers, provided that such are available. In the remotely controlled station, the alternator is equipped with an amortisseur winding and is started as an induction motor. As the alternator comes to synchronism the exciter builds up voltage and excites the alternator field, thus pulling the alternator into step. Ammeters, which are provided in the control station, indicate when the alternator pulls into step, and the operator then opens the fractional voltage supply and closes the line oil circuit breaker, thus applying full voltage to the remotely controlled alternator. The closing of the oil circuit breaker causes contactor A, to close, which applies full excitation to the alternator and opens the water wheel gate to full gate position. The gate motor is operated from direct current supplied by the exciter. To close down the remotely controlled alternator, the operator opens the oil circuit breaker in the main station. The alternator then speeds up, and centrifugal switch B, breaks the coil circuit of contactor A, which drops out and completes a circuit to close the gate. The contactor is arranged to insert resistance in the exciter field circuit, which prevents the alternator voltage rising above normal value.

Time delay features prevent the station dropping out until an appreciable period has elapsed, sufficient to take care of the normal service stops for discharging and taking on passengers.

In the absence of manual attendants, the automatic sub-station is amply protected by reliable devices performing certain functions, which in the manual sub-station would be taken care of by the operator; such as to:

1. Start machines when demand exists or at direction of remote control.

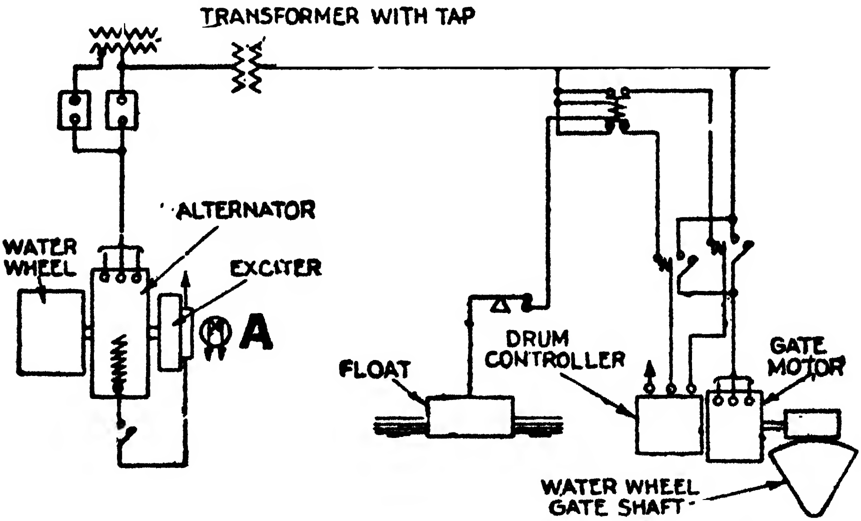


FIG. 4,785.—Control system for an entirely automatic station (drum controller required). The entirely automatic station differs from the remotely controlled station in that the power line does not necessarily pass through a manually operated plant but may be tapped directly into the transmission network. The contacts of the float switch close when the water level in the forebay rises to a predetermined level, thus energizing a relay and causing the contactor in the gate motor circuit to close. The closing of this contactor applies voltage to the polyphase gate motor, which is connected to the water wheel wicket gate through proper gearing. The motor opens the gate approximately 20% of full gate opening, which admits sufficient water to start the water wheel. At 20% gate opering, the gate motor-contactor is dropped out by the breaking of its coil circuit, which is opened by one of the drum controller segments, the drum controller being driven through suitable gearing by the gate motor. The wicket gate stays in the partially open position until the water wheel

2. Protect machine against injury during starting.

3. Connect machine to sub-station bus.

4. Protect machine against injury due to any cause while running.

5. Shut down machine when demand ceases or remote control indicates.

In some of these operations, such as protection against excessive temperature of load limiting resistors, or machine windings, the machine is shut down until the temperature has dropped sufficiently to make operation safe. At this time, the machine again automatically resumes service. Where the shut down is due to other causes, an inspection may be required and the machine is not started again until the cause of the interruption has been determined and corrected.

Scheme of Operation.—From the simplified wiring diagram, fig. 4,786, covering a typical 600 volt, synchronous converter installation, the general method of operation can be studied in detail. This diagram is so arranged that the various operations are indicated in sequence, beginning at the left. The starting indication is given by a voltage relay, which functions on low trolley voltage and operates through a time-delay starting relay (No 2) to start the station. After this relay has operated, provided the

FIG. 4,785.—*Text Continued.*

comes to nearly synchronous speed, when the contacts of centrifugal switch A, driven from the shaft of the alternator, close, thus bridging the break in the drum controller segment and causing the gate motor to continue to open the gate. The proper segment on the drum controller then causes the fractional voltage oil circuit breaker to close, thus connecting the alternator to the fractional voltage transformer taps. A drum controller segment, then making contact, causes the alternator field contactor to close, the closing of which excites the alternator, pulling it into step. By means of controller segments operating on the proper control circuits, the fractional voltage oil circuit breaker is tripped, and the main line oil circuit breaker is closed. The alternator is thus properly connected to the bus and operates at a load corresponding to the head of water available. If the level of the water in the forebay fall to a predetermined minimum, the station is automatically shut down. Where the head of water is constant and full kilowatt output from the alternator is desired at all times, the motor operated wicket gate may be dispensed with and the water wheel provided with fixed wicket gates. A motor operated or hydraulically operated valve can then be used for starting and stopping the station.

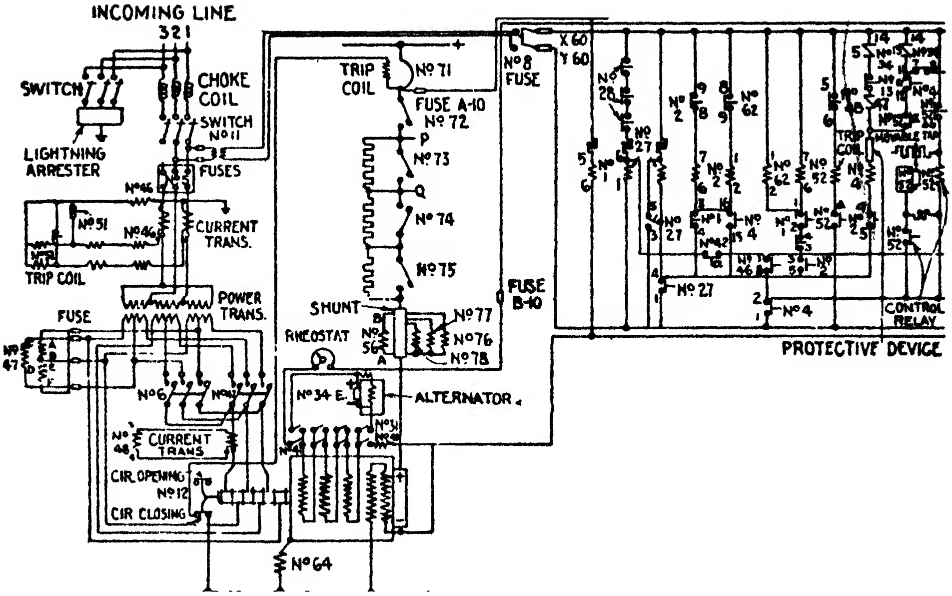


FIG. 4,786.—Wiring diagram of a typical automatic sub-station.

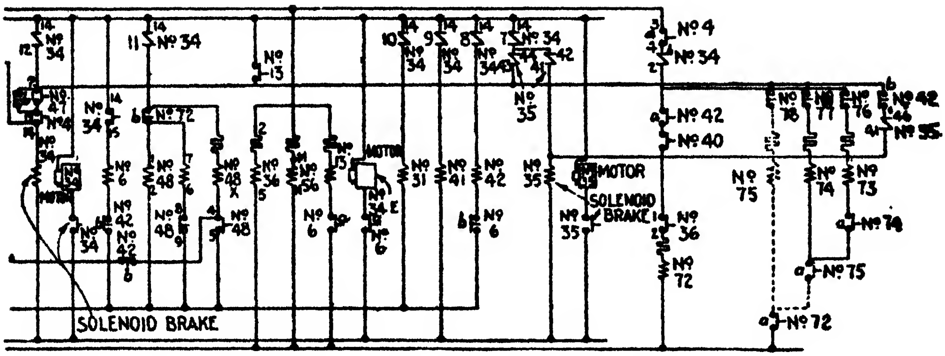
1. Master starting element
2. Time delay starting relay
4. Master control contactor
6. Starting contactor
8. Control power switch
11. Control power transformer
12. Speed limit switch, hand reset
13. Synchronous speed control relay
27. A-c. undervoltage relay
27X. Auxiliary relay for No. 27

various protective devices give correct indication, the master control contactor (No. 4) is closed. This actuates the motor mechanism of the oil circuit breaker which closes the breaker, thus energizing the *a.c.* bus.

The protective devices again giving correct indication, the motor of the master switch, or drum controller (No. 34) is then energized and the drum starts to rotate. From this position the drum controller directs the sequence of operations. About 30 seconds is required for a complete revolution of this drum (from starting to running position, 23 seconds).

A segment of the drum controller closes the starting contactor (No. 6), connecting the converter to reduced voltage taps on the transformer. At the same time the field-flashing motor generator, which is used to insure correct polarity, is started.

When the converter reaches synchronous speed, as indicated by a relay connected across the armature of the converter, the converter field is separately excited by the closing of contactor (No. 31), which connects the field to the field flashing generator.

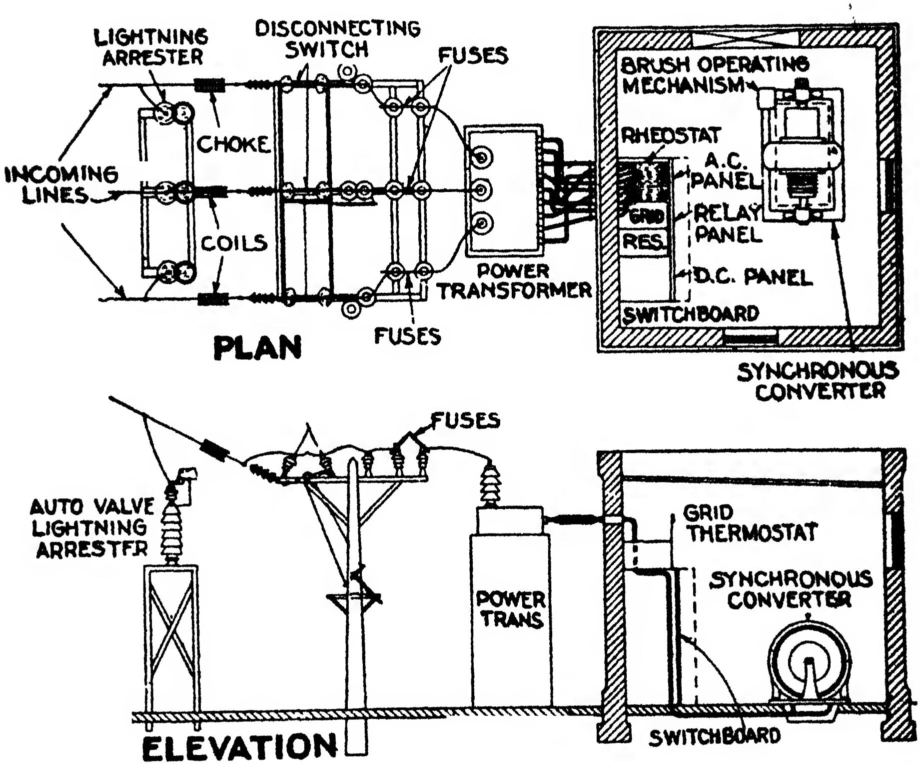


28. Resistor temperature relay
31. Field flashing contactor
34. Master switch
34E. Field flashing motor generator set
35. Brush operating mechanism
36. Polarized relay
38. Bearing temperature relay, hand reset
40. A-c. machine field relay
41. Full field contactor
42. Running contactor
46. Balanced current relay
47. Potential reverse phase relay
48. Starting protective relay
48X. Auxiliary relay for No. 48, hand reset
49. A-c. machine temperature relay
51. A-c. overload time delay relay
52. Oil circuit breaker and mechanism
56. D-c. reverse power and underload relay
62. Time delay stopping relay
64. D-c. grounding protective relay, hand reset
71. D-c. line circuit breaker
72. D-c. line contactor
73. Load limiting resistor short circuiting contactor
74. Load limiting resistor short circuiting contactor
75. Load limiting resistor short circuiting contactor
76. D-c. overload relay
77. D-c. overload relay
78. D-c. overload relay

After sufficient time has elapsed to insure the establishment of correct polarity, the separately exciting field contactor is opened and the self-exciting field contactor is closed. The machine is now running at synchronous speed, self-excited, but on half voltage taps. The starting contactor (No. 6) next opens and the running contactor (No. 42) closes almost simultaneously, connecting the converter to full voltage taps on the transformer. The converter brushes are lowered by the motor operated brush operating mechanism. The machine is now delivering normal voltage with correct polarity. The *d.c.* line contactor (No. 72) next closes, connecting the converter to the *d.c.* bus through load limiting resistors. The load limiting resistors serve to limit the current when the machine is connected to the bus and are short circuited, in two or three steps, to further cushion the machine on the bus.

The controller has now reached the full running position and the motor circuit is opened, stopping the controller until the machine is ready to shut down.

Under normal operation, the station shuts down when the load falls below a certain predetermined amount. By the use of the time delay feature, the actual shutting down does not take place until after the load has remained below the underload setting for a certain definite interval.



FIGS. 4,787 and 4,788.—Plan and elevation of typical outdoor semi-automatic sub-station.

At the end of this time interval, the contactor (No. 4) opens the oil circuit breaker (No. 52), the running contactor (No. 42), and the line contactor (No. 72).

The drum controller then returns to the "off" position and the

equipment resumes a position ready to respond to the starting indication resulting from the next reduction in the trolley voltage.

Semi-Automatic Sub-Stations.—By definition this type of station is *one which is started manually and runs until shut down, according to some schedule, by one of a number of different methods.*

These methods may be a time switch, momentary interruption of *a.c.* supply, or by an attendant who enters the substation for that purpose.

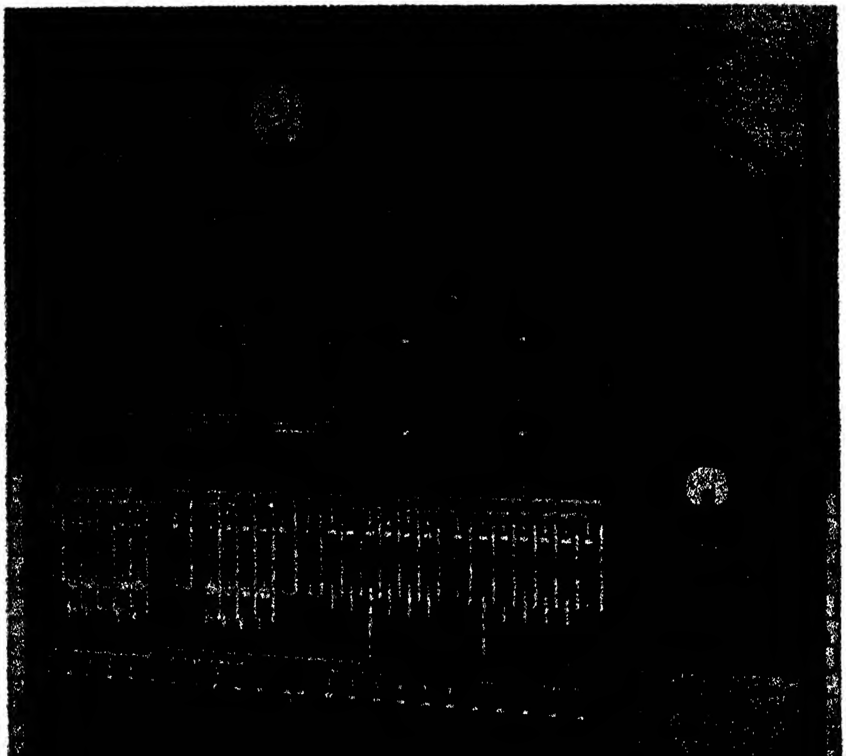


FIG. 4,789.—Westinghouse synchronous visual type supervisory apparatus; dispatcher's control keys and indicating lamps.

Since the semi-automatic sub-station is attended only during the starting and possibly the shutting down period, it must be equipped with all protective devices such as are included with full automatic equipment. These devices include those to prevent open phase running, excess temperature of machine or transformer windings, overheated bearings, operation with open shunt field winding, and overspeed of the machine. Of course, complete automatic operation of the *d.c.* equipment is essential.

Since the station runs continuously during its scheduled period of operation there will be no saving in light load losses, such as would be effected by a full automatic equipment.

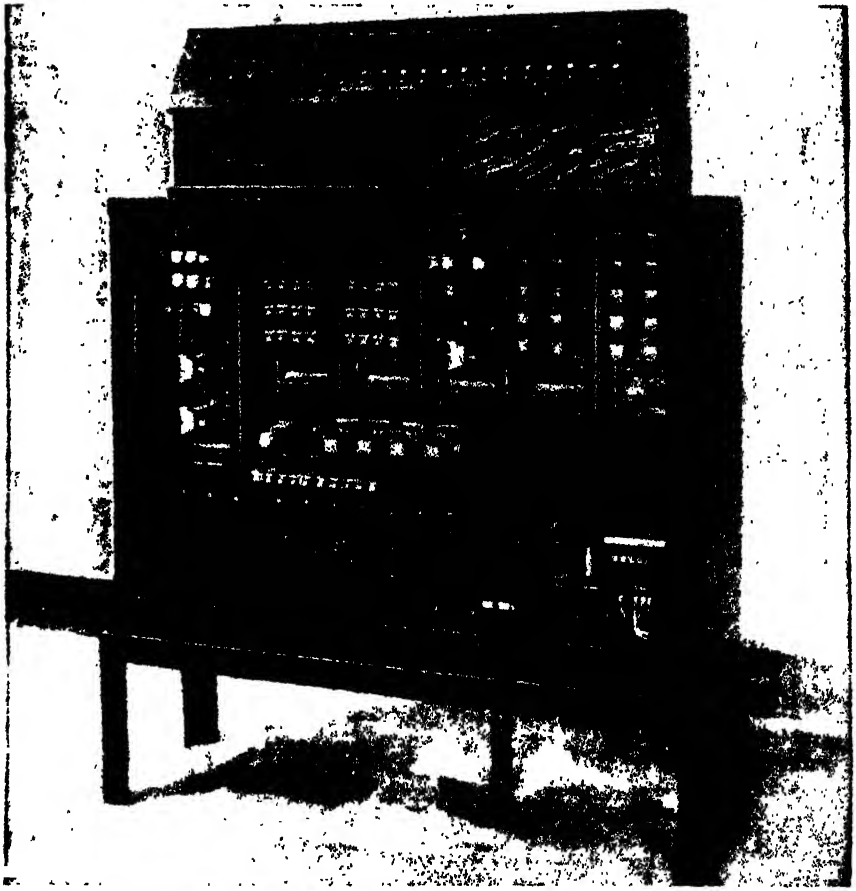


FIG. 4,790.—Westinghouse code visual type supervisory control apparatus; dispatcher's control and relay combined

Load requirements, however, may be such as to make this item negligible. The item of attendance is not entirely eliminated.

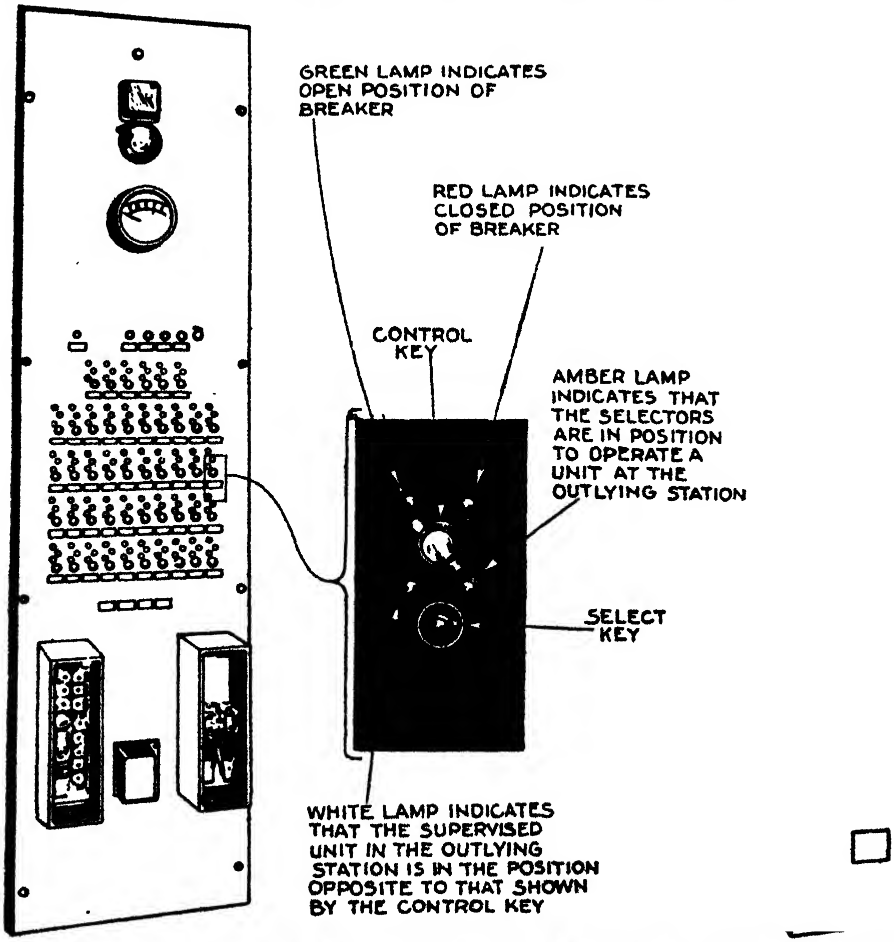
Automatic Supervisory Equipment.—The ordinary automatic sub-station operates very satisfactorily and would meet all requirements were it not for the occasional unusual occurrence which is foreign to any predetermined set up, but which is nevertheless vital to unit operation.

For example, to meet emergency conditions in this class of service, it is essential that means be provided for quickly opening all feeders supplying a particular trolley section. In many installations where load conditions permit, it has also been found profitable and advisable to shut down and lock out certain automatic sub-stations during light load period. There is a demand, therefore, for some means of supervising these unattended automatic sub-stations from a central point of dispatcher's station.

Figs. 4,791 and 4,792.—Westinghouse audible type supervisory control apparatus; fig. 4,791 dispatcher's control equipment; fig. 4,792 sub-station relay cabinet.

A new class of equipment has been developed and is known as *automatic supervisory equipment.* This equipment *provides the dispatcher with a means of selectively controlling devices in the sub-stations and automatically gives him a visual indication of the sub-station apparatus by means of standard indicating lamps located in cabinets at his office.*

There are several types of equipment to meet various requirements and designated by the manufacturer as:



FIGS. 4,793 to 4,795.—General Electric supervisory equipment: *Dispatchers' control equipment.*

1. Synchronous visual type:
2. Code visual type;
3. Audible type;
4. Synchronous selector type.

The first two types give the dispatcher a continuous visual indication of the position of the apparatus controlled, while the third type gives an audible signal such as a bell tap or buzzer tone, informing the dispatcher of the conditions existing in the sub-station.

A detailed description of the synchronous selector system as made by the General Electric Co. is here given to illustrate automatic supervisory control. The dispatcher's office equipment consists of control keys, indicating lamps, and necessary supervisory devices for receiving control impulses which indicate the positions of the various supervised units.

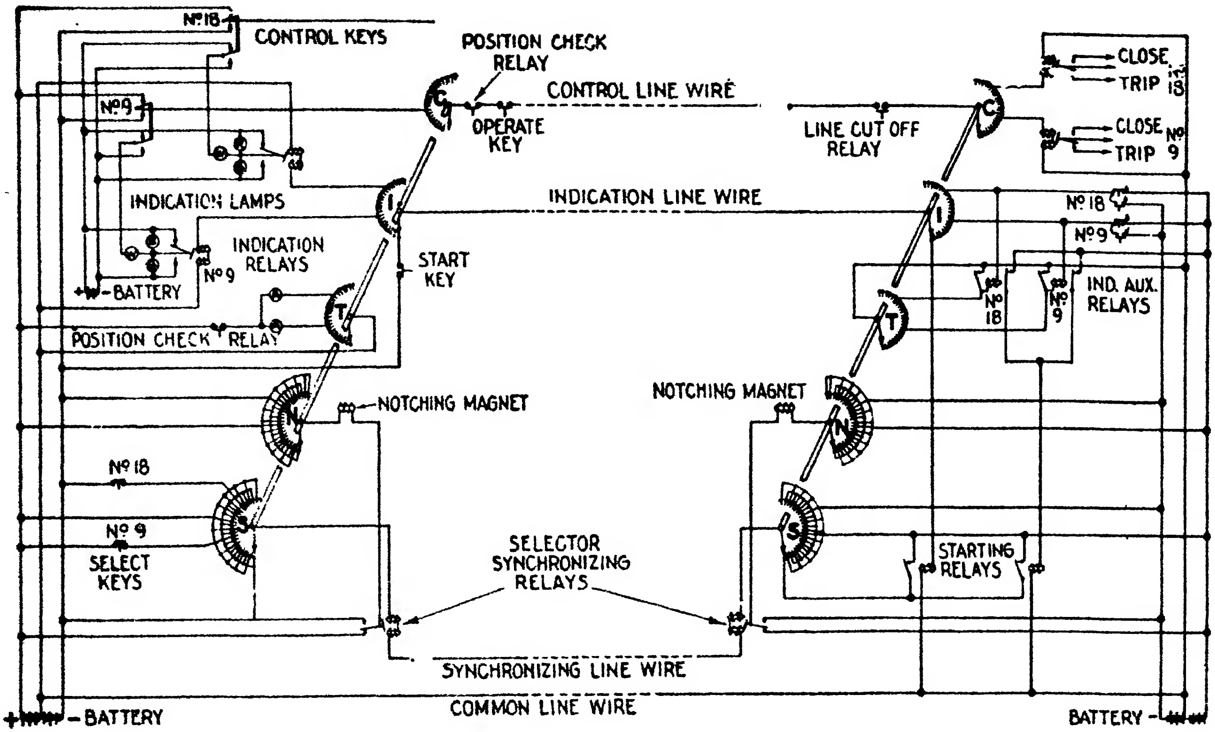
The sub-station equipment consists of the supervisory devices which transmit the control impulses to the auxiliary control relays and send back indication impulses to the dispatcher's office.

At the dispatcher's office, each supervised unit has a key and lamp combination consisting of a standard two position turn key for control, a red light for indicating the closed position, a green light for indicating the open position, and a white light for indicating an automatic operation of the corresponding breaker unit. Each combination has a two position push and pull selecting key to stop the selectors at a point corresponding to the unit it is desired to control, and an associated amber lamp for indicating when the selectors are connected to that particular unit, as in figs. 4,793 to 4,795.

The dispatcher controls the supervised unit in the sub-station over the control circuit, and the indications from the supervised units are returned to the dispatcher over the indication circuit.

The equipment at the sub-station is made to operate in synchronism with the equipment in the dispatcher's office by means of current impulses sent over the synchronizing circuit.

The schematic diagram shown in fig. 4,796 gives the control



FIGS. 4,796 and 4,797.—General Electric supervisory equipment; fundamental circuits. See text.

NOTE.—General Electric supervisory equipment. *Synchronizing selector unit No. 2 for dispatcher's office.* See fig. 4,793 There are ten relays on dispatcher's panel used to perform auxiliary and protective functions. These are mounted in a case at the lower left side of the panel and designated A, B, C, D, E, F, H, K, M, and S. A, is a position check relay so connected that it will drop out immediately if for any reason the selectors in the substation fall out of step with the selectors in the dispatcher's office. Relay A, is also deenergized while the selectors are in motion. When the selectors stop in synchronism on

control point relay, A, picks up and energizes the auxiliary position check relay B, which must pick up before time delay relay C, drops out. If relay A, then momentarily opens its contacts through loss of synchronism, between selectors, relay B, cannot again be energized until after a subsequent stepping operation of the selectors. If relay B, be deënergized, it opens the control circuit, thus preventing the possibility of performing a false operation. It also opens the circuit to the associated amber lamp, thus notifying the dispatcher of this condition. Relay C, is energized only when relay D, is deënergized and has a slight time delay in dropping out. These two relays hold open the synchronizing circuit for a short interval when the selectors reach the zero position. This insures that the dispatcher's office selector stops on the zero or starting position. Relay C, because of its time delay drop-out characteristics, also prepares the pick-up circuit for relay B, when the equipment is stopped on a control point. Relay E, is the starting position relay which functions to pick up and close its contact in the coil circuit of relay F, when the control, common, and synchronizing lines, are in their normal condition and the selectors are on zero. Relay H, the indication line check relay, will also pick up and close its contact in the coil circuit of F, when the indication line is in its normal condition and the selectors are on zero. Through the contacts of relays E, and H, the coil of F, the auxiliary starting position relay, is energized. This relay closes contacts to light the starting position lamp and to prepare the starting circuit through the start key. It also operates two sets of transfer contacts, one lighting the pilot light and the other, in conjunction with relay K, establishing the alarm-bell circuit. Bell relay K, is normally picked up through the upper set of transfer contacts of relay F, and one of its own contacts. This transfer contact momentarily opens the coil circuit K, when F, picks up, indicating the equipment has stopped on zero, or when F, drops out because of the equipment automatically starting from zero. This deënergizes relay K, and causes the alarm bell to ring. Provided the bell key is turned to the single-stroke position bell, reset relay S, will be energized through the bell key and a contact of relay K. After the bell has given a single stroke, relay S, will pick up. Its contact completes the coil circuit of relay K, which recloses and deënergizes S. With the bell key in the "continuous" position, relay S, cannot be energized. The bell will ring until the operator moves the bell key to the "single stroke" position which will pick up S, to energize K.

circuits for only two units, numbered 9 and 18. It is understood of course that each selector unit is capable of handling 23 such circuits.

Operation of Synchronous Selector System.—Briefly, the functioning of the system, beginning at the dispatcher's office, is as follows:

Assume the system at rest. Before the dispatcher tries to perform any operation, he has to note that the white lamp associated with the start key is lighted, which

indicates that the selectors in the dispatcher's office and the outlying station are both in the zero, or starting, position.

In case this white light be not burning, the dispatcher should synchronize the selectors in both stations by pushing the synchronizing key. It is not possible to operate the system if the selectors be not both in the zero, or starting, position.

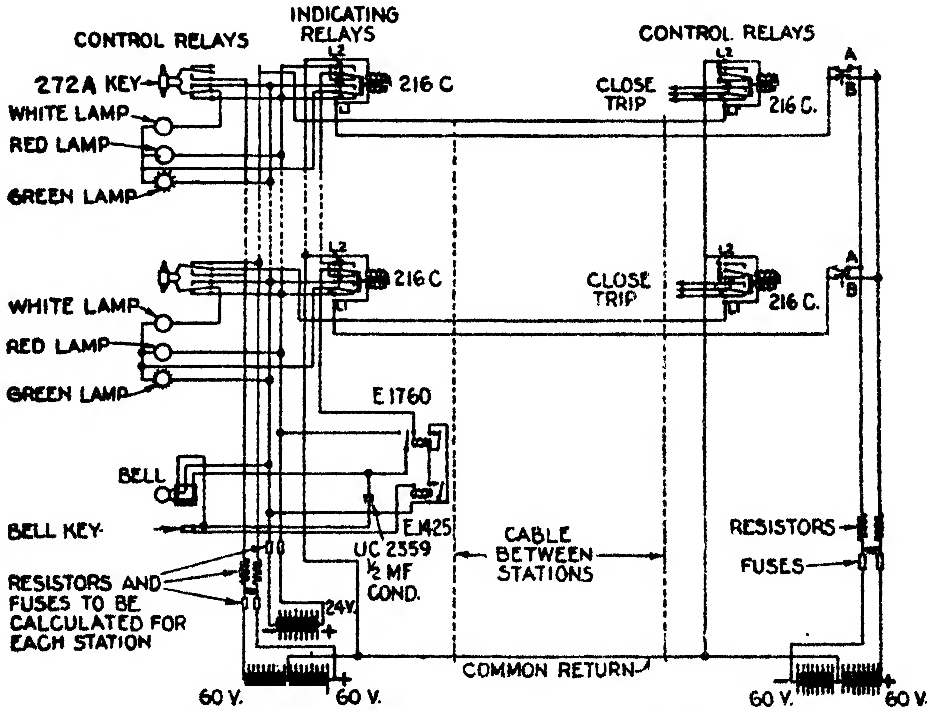


FIG. 4798.—Diagram of General Electric automatic supervisory equipment, cable type, for control and indication of remote power apparatus. *To operate* a breaker at an outlying station, the dispatcher turns the key assigned to that unit. If the breaker be closed, the red lamp lights and the green lamp goes out to indicate a completed operation. The white lamp remains lighted only during an operation, and goes out when the breaker closes. This lamp also lights when a breaker trips automatically and remains lighted until the dispatcher acknowledges the same by turning the key associated with it to the "trip" position. This operation makes a set up on the auxiliary relay at the breaker so that it can be closed when the key is turned to the "closed" position. A trip free contactor is used to allow the breaker to open if closed on an overload or short circuit, and thus prevents a pumping action since the dispatcher's control key is turned to the "closed" position. The connection diagram gives complete connections for two operating keys of the dispatcher's control cabinet.

Whenever the dispatcher desires to operate any oil circuit breaker or equivalent unit located in the outlying station, he first *pulls* the selecting key associated with the unit he desires to operate. By pressing the start key, the selectors at each station step in synchronism to the selected position and stop; the associated amber lamp lights, indicating that the selectors have reached the desired position. A control and an indicating circuit for that unit are now connected to the control and indicating wires, and the dispatcher can perform the desired operation by turning the individual control key and pressing the master operating key. The changed position of the supervised unit will be indicated at once by the red and green lamps. Upon completion of this operation, he *presses* the selecting key, which permits the selectors to return automatically to the zero position.

The pilot light key should also be depressed to extinguish the pilot lamp so that it will be ready for the next operation.

Upon reaching the zero position, the alarm bell (either single stroke or continuous ringing) rings and the white lamp is lighted, indicating that the system is ready for a new operation. However, if he so desire, the dispatcher can select successively any number of positions during a single rotation, provided they be taken in sequence.

With the supervisory system at rest, assume an automatic operation of an outlying station breaker.

The breaker auxiliary switch starts selectors which automatically check the position of all units supervised. During the operation, an indication is sent over the indicating wire to light the correct indicating lamp in the dispatcher's office, and the alarm bell calls the dispatcher's attention to this. Also the individual white light for this unit is lighted, so that the dispatcher can easily locate the unit which has operated. Similar operation takes place in case of simultaneous operation of more than one outlying station unit.

The dispatcher can extinguish the white light and reset the trip free device for the breaker by selecting the supervised breaker and turning the control key so as to correspond with the position of the breaker.

If, for any reason, such as inductive interference, the dispatcher's office and the outlying station selectors are thrown one notch out of step, the selectors stop immediately, and the dispatcher cannot perform any control operations. Thus no false operation can take place. The dispatcher has to push the synchronizing key, return the selectors to the zero position and start the operation all over again.

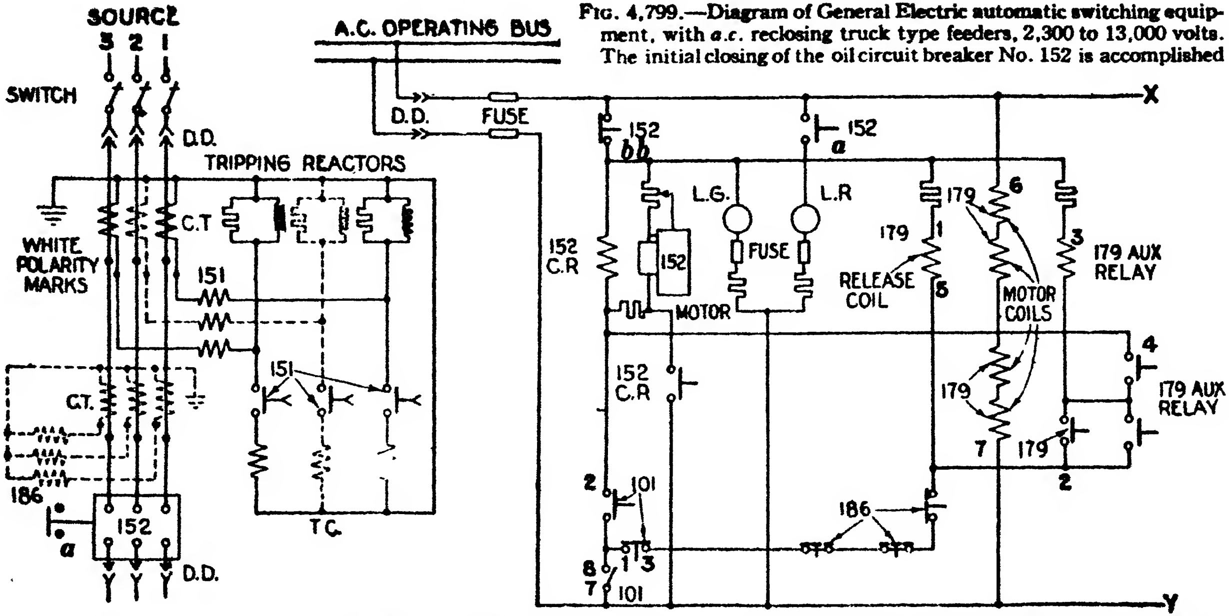


FIG. 4,799.—Diagram of General Electric automatic switching equipment, with *a.c.* reclosing truck type feeders, 2,300 to 13,000 volts. The initial closing of the oil circuit breaker No. 152 is accomplished by operating the C, button (contacts 1-2) of the master element No. 101. The breaker control relay is energized and sealed in until the closing operation is completed. When No. 152 is tripped on over current by over current relays No. 151, the release coil of No. 179 is energized and the motor (which is energized continuously) is allowed to rotate. After a time delay the first arm of No. 179 closes contacts 2, energizing the auxiliary relay which seals in. After a short interval the first arm closes contacts 4, energizing the control relay and reclosing No. 152 for the first time. The motor of No. 179 continues to rotate and, if the overload persist, No. 152 is similarly reclosed two more times by the second and third contact arms of No. 179. If No. 152 be open after the third arm of No. 179 passes the contacts, the release coil is energized and the stop on its plunger engages the locking out arm, preventing further rotation of the contact arms. No. 179 must then be reset by pushing in the reset button of No. 179. The equipment must then be placed in service manually by operation of No. 101. If No. 152 remain closed (owing to disappearance of overload after any reclosure) the release coil of No. 179 is de energized and the reclosing relay returns to normal position ready for a new cycle. Contacts 7-8 of No. 101 are open when truck withdrawing mechanism is in tripping position, or No. 152 is tripped by No. 101. Automatic reclosing operation is suspended until contacts 7-8 are closed by operating the C, button of No. 101. ***Legend***—C.T., current transformer; T.C., trip coil; C.R., control relay; D.D., disconnecting device;

The position of all units indicated may be checked at any time by pushing the starting key.

A trip free feature is incorporated in the auxiliary relay equipment at the outlying station. A breaker when tripped open by a protective device, therefore, cannot reclose until this trip free device has been reset (except in the case of automatic reclosing equipments).

The dispatcher resets the trip free device by performing the same operation as that for tripping the breaker.

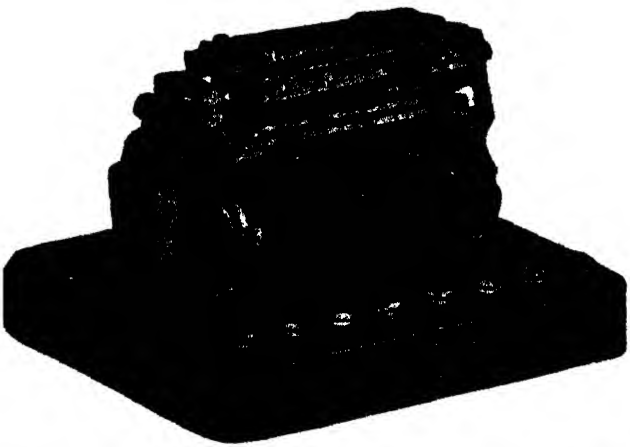


FIG. 4,800.—General Electric supervisory equipment: *Selector synchronizing relay.*

Operation of Circuits.—As previously stated, the schematic diagram of the synchronous selector system shown in fig. 4,796 gives the control circuits for only two units, numbered 9 and 18. It is understood, of course, that each selector unit is capable of handling 23 such circuits.

Synchronizing Circuits.—The function of this circuit is to provide a means for forcing the selector in the sub-station to operate in exact synchronism with the selector in the dispatcher's office. At each end of the synchronizing line and connected in series with it, is a polarity relay used

FIG. 4,799.—*Text continued.*

L.G., green lamp; L.R., red lamp; a, circuit closing auxiliary contact; bb, auxiliary contact, closed when mechanism is in open position; 101, master element; 151, *a.c.* over current relay; 152, oil circuit breaker and control relay; 179, *a.c.* time delay reclosing relay; 186, locking out current relay.

as a selector synchronizing relay. Since the two relays are in series with each other, they will operate together whenever a current impulse is sent over the synchronizing line.

The circuit for the two relays is completed at each end of the line through the synchronizing bank of the selector.

The current impulses are fed into the synchronizing line with alternate polarity, as successive contacts on the synchronizing bank of the selector are connected to opposite polarity. The contacts on the selector synchronizing relays operate the matching magnets of the selectors by applying alternate polarity at each step to one side of the notching coil. This circuit is completed to opposite pressure through the contacts of the notching bank.

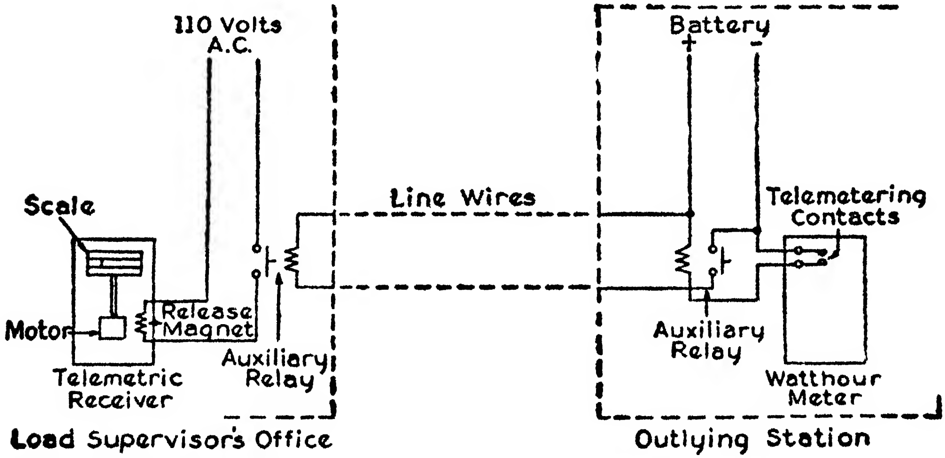


FIG. 4,801.—Diagram of General Electric automatic telemetering equipment, frequency impulse system. *Operation:* Consider a totalizing watt hour meter, equipped with telemetering contacts and located at an outlying station. These contacts operate an auxiliary relay which transmits the impulses from the watt hour meter over the line wires to the load supervisor's office. The impulses are received by auxiliary relays which transmit them to the recording and indicating telemetric receiver. Since each revolution of the watt hour meter shaft causes the telemetering contacts to send out a definite number of impulses, each impulse represents a definite block of power. Therefore, the rate of power with respect to time represents the actual *kw.* measured. The receiving telemeter is calibrated so that a certain number of blocks of power, or impulses per second, will bring the pointer of the telemeter to its full scale reading, or a definite part of full scale, the pointer indicating and a pen recording this position or the *kw.* load. The apparatus is accurate within 2% of full load.

NOTE.—General Electric supervisory equipment: *The selector unit.* The principal device used in this system is the selector unit operating in conjunction with the selector relay unit. It is located at the lower right hand corner of the dispatcher's panel, shown in fig. 4,793, and consists of five rows or banks of 25 contacts each, making a total of 125 contacts arranged in a semi-circle. There are five wipers, or armatures, one for each bank of contacts mounted

The initial or starting impulse is given when the dispatcher presses the start key. The pumping action of the selector synchronizing relays is then continued as long as the relays receive alternate positive and negative impulses from the contacts of the synchronizing bank. As soon as a contact is reached that is disconnected from the source of voltage, the selectors will stop.

The dispatcher can disconnect any one of the contacts from the source of voltage by opening the circuit of that contact with the corresponding select key. It is in this way that the dispatcher chooses the supervised unit to be operated. After opening the proper select key, a press of the start button will give the initial impulse and start the selectors. They will continue to run until the open contact is reached. Both the selector in the dispatcher's office and the sub-station selector will stop on the open contact. The wipers on all the other banks will be on the corresponding contact on those banks.

Control Circuit.—With the selectors in the dispatcher's office and the sub-station stopped on corresponding contacts, a direct connection is made between the control key and the control relay of the supervised unit corresponding to the position of the selectors. By turning the control key to one position or the other, the control line wire is connected to positive or negative pressure.

At the sub-station end, the control relay, being polarized, responds to the polarity of current and operates to close or trip the device under its control.

NOTE—*Continued.*

on a common shaft, that move over the semi-circle of contacts touching each of the stationary contacts in succession. Each armature or wiper is insulated from the others and has a separate lead making a total of 130 connections to the selector. A driving magnet actuates the armatures by means of a notching arrangement. Each time the coil is deënergized the armatures are moved from one contact to the next. The five banks of contacts are known as the synchronizing, notching, control, indication and transfer banks corresponding to their functions. The synchronizing bank sends out alternate contacts and negative impulses of current over the synchronizing line, and for this reason alternate contacts of the synchronizing bank are connected to positive and negative polarity. These connections are made through the normally closed contacts of the select keys. The function of the notching bank is to reverse the current through the driving magnet of the selector in order to control its operation so that only one step at a time is taken. The alternate contacts of this bank are connected directly to positive and negative polarity. The function of the control bank is to connect the control line wire to the control keys in succession. Therefore, each contact on the control bank is connected to the corresponding control key, and the armature is connected to the control line wire through the proper protective relays. The function of the indication bank is to connect the indication line wire to the indication relays in succession. Therefore, each contact on the indication bank is connected to the coil of the corresponding indication relay, and the indication line wire is connected to the armature. The function of the transfer bank is to cause the amber lamp on the control unit to light when the selector stops on the corresponding contact.

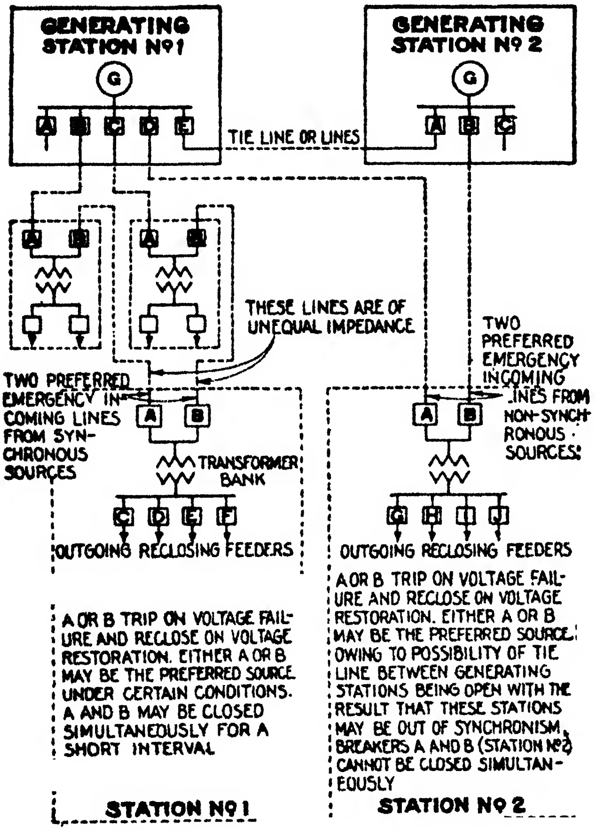


FIG. 4,802—Diagram of General Electric preferred emergency operation of power line system for automatic station control. *Operation:* At Station No. 1, when under voltage occurs on any phase of the preferred line, its under voltage relay starts to drop out and after a short time-delay closes a set of contacts. If conditions on the emergency line be satisfactory for a transfer, a timing relay having a relatively longer setting than the under voltage relay is placed in action. This relay shown in the lower right corner of the upper panel section is energized from the emergency line but controlled by the under voltage relays on the preferred line. It prevents a transfer as a result of momentary voltage "dips" and also permits any protective scheme to operate and clear the fault which may cause such "dips." If under voltage conditions on the preferred line continue (usually from 5 to 10 seconds or longer), the breaker on this line trips. The tripping action is accomplished by voltage from the emergency line. As soon as the preferred breaker opens, the emergency breaker closes. The control is so interlocked that when a transfer is made in this direction, the preferred breaker must be open before the emergency breaker can close. This arrangement is necessary because a fault might exist on the preferred line and if both breakers be closed simultaneously the fault would be reflected to the emergency line. This would probably result in a loss of station voltage and would, thereby, eliminate the means of opening the preferred breaker (over current protection is usually omitted and only voltage tripping is ordinarily used). Therefore in making this transfer the load is momentarily dropped. However, if voltage remain on the emergency line, and also return to the preferred line for a definite time, the preferred breaker then closes, after which the emergency breaker immediately opens. This temporary overlap is so short that protective relays will not operate and it results in a re-transfer without dropping the load. With a slight variation, the equipment described can be applied to incoming lines from non-synchronous sources (see Station No. 2). In this case, however, a momentary dropping of the load occurs in the transfer both to and from the emergency source. Other modifications of these equipments can be made to suit service requirements.

A positive impulse is sent to trip the device and a negative impulse to close it. As long as the selectors are standing at this point, the dispatcher may trip or close the device at will.

Indication Circuit.—The function of the indication circuit is to notify the dispatcher of a change in the position of any device at the sub-station by extinguishing one lamp and lighting another. A white lamp is also lighted to indicate which of the devices operated.

Assuming that the selectors are standing on one contact as described above, the indication circuit functions to indicate that a change has taken place each time the dispatcher opens or closes the device.

The auxiliary switches on the supervised unit connect the indication line to either positive or negative polarity, depending upon which switch is closed.

A current impulse is sent over the indication line to the indication relay in the dispatcher's office. This relay operates to light a green or red lamp, indicating that the device is open or closed.

After the dispatcher has completed the operation, the selectors may be reset to the zero position by closing the select key. Proper polarity is thereby supplied to start the selectors, which continue to run until the zero position is reached.

NOTE.—General Electric supervisory equipment: ***Transfer selector.*** Since the selector unit has only 23 positions that can be used for control and indication, another selector is required for each group of 23 units supervised. In order to transfer the synchronizing and notching circuits from the first to the second selector, from the second to the third, and so on, a transfer selector is required. This selector is the same as the first, except that only four banks of contacts are required.

NOTE.—General Electric supervisory equipment: ***The auxiliary relays.*** The five auxiliary relays are lettered A, B, C, D and F. Relays A and B, are the two starting relays. Relay A, is energized over the indication line wire when the dispatcher presses the start key, and picks up to give the initial starting impulse to the selectors. Relay B, performs the same function, but is energized whenever one of the indication auxiliary relays drops out because of a change in position of the supervised units. Relay C, is a line cut off relay that holds open the control line as long as the selectors are in motion. Relay D, is a voltage indication relay connected across the power supply. If any fuse blow, or power supply be lost for any other reason, relay D, opens the common line wire to prevent operation of any sort. With the selectors in the zero position when voltage is lost, the dispatcher is warned by the alarm bell and loss of the starting position lamp. Relay F, is used to check the synchronizing line wire, being deënergized in the starting position if the line wire be open. This relay is also deënergized as soon as the selectors start from the zero position.

NOTE.—General Electric supervisory equipment: ***The indication auxiliary relay.*** These relays are normally picked up and are connected between either positive or negative power and neutral, by the auxiliary switches on the supervised units. A change in the position of a supervised unit will cause the indication relay to fall out. This causes the selector to start, if it be in the proper position, and the indication relay picks up, sealing itself in. The proper indication at the dispatcher's office is therefore assured.

In case any of the supervised units changes position while the selectors are in the zero position, the circuit for the corresponding indication auxiliary relay is broken by the action of the auxiliary switches on the supervised unit. The indication auxiliary relay drops out and completes a circuit for a starting relay which, in picking up, sends the initial impulse

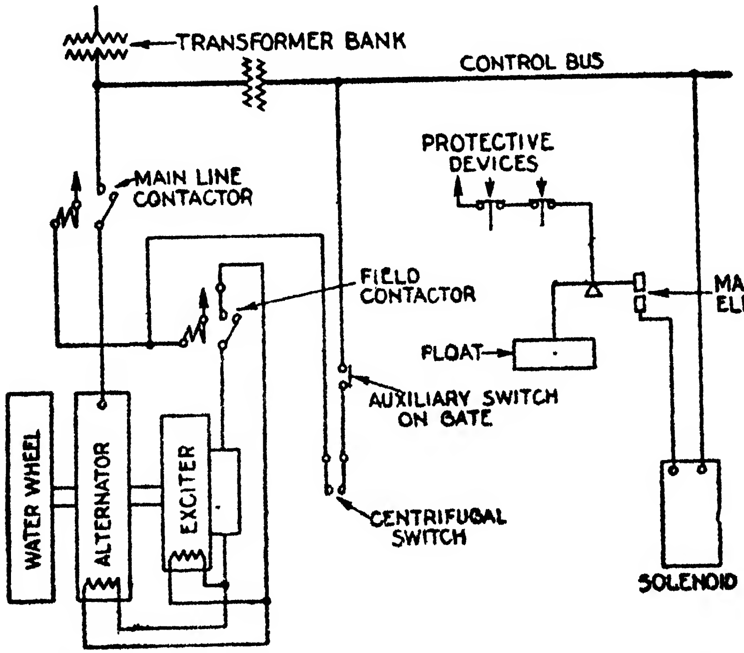


FIG. 4,803.—A system of control which is adaptable to many automatic alternator installations (drum controller not required). This system involves the use of a master starting element, shown in the diagram as a float switch, but which may be either a frequency controlled device, a pressure governor, or a relay energized over pilot wires, or any other device, which when operated, will close the circuit of a solenoid or other starting device to admit water to the water wheel. When the water wheel comes to approximately 90% of synchronous speed, the contacts of the centrifugal switch close, which complete the circuit through an auxiliary switch attached to the gate mechanism to close the main line and the alternator field contactors. The closing of the alternator field contactor also completes the field circuit of the exciter. Owing to the time lag in the building up of its own field, the exciter excites the alternator an instant after the closing of the main line contactor, which pulls the alternator into step with a minimum disturbance to the system. The alternator, thus properly connected to the line, will carry its share of the system load when a governor is used, but when the gates are motor or hydraulically operated, the load will depend upon the degree of the gate opening. When the master element opens the circuit of the starting device, or when the protective devices wired in series with the contacts of the master element operate, the station will close down. In closing down, the load on the alternator is first reduced, and then the main line and field contactors are opened by an auxiliary switch which is operated from the gate mechanism.

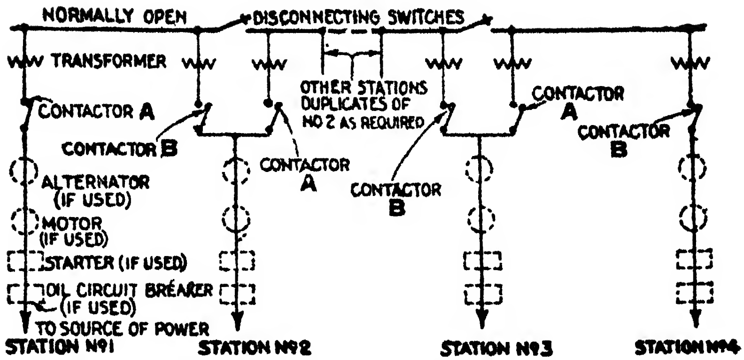


FIG. 4,804.—Diagram of General Electric automatic switching system, for *a.c.* railway signal and train control feeders. Two classifications of feeder equipments are made: 1, operation *without a.c.* reclosing relay; 2, operation *with a.c.* reclosing relay The operation is described for any section of the line, a section consisting of the line with an A, contactor at one end and a B, contactor at the other.

Class 1.—With automatic resetting feature —Assume normal line conditions with contactor A, closed and B, open. If a trouble occur on the line, A, trips on overcurrent. After a short interval of two or three seconds, B, closes If the trouble clear, B, remains closed. A, remains open, but resets ready for reclosure, with a two or three second delay if B, open later. If the disturbance persist, B, trips and locks open. A, is also locked open. After the trouble is corrected A, is reset manually and normal operation is resumed.

Class 2.—Without automatic resetting feature.—Assume normal line conditions with A, closed and B, open. In case trouble occur, A, trips and is locked open until manually reset. After a brief interval of two or three seconds B, closes. If the line clear B, remains closed If the disturbance persist, B, trips and is locked open until manually reset.

Class 3.—With complete automatic resetting feature.—Using an *a.c.* reclosing relay to control the A, contactor, assume normal conditions with A, closed, and B, open. If trouble occur on the line, A, trips on overcurrent and after a brief interval of two or three seconds, B, closes. If the line clear, B, remains closed, and A, remains open, but resets ready for reclosure in two or three seconds if B, open later. If the disturbance persist, B, trips and locks open. After a time delay, A, recloses. If the trouble still remain until the last reclosure of A, by the reclosing relay, it is assumed to be permanent, A and B, then locking open. After the trouble is corrected A, is reset manually and normal operation is resumed. If the line clear before the last reclosure of A, this contactor remains closed. After a time delay to insure voltage is being maintained, B, resets ready for reclosure in two or three seconds if A, opens later.

Class 4.—With partial automatic reset.—Assume normal conditions with A, tripping on overcurrent and B, closing as described above. If the line clear, B, remains closed, and A, remains open with resetting mechanism ready for a time delay reclosure if B, open later. If the trouble persist, B, trips and locks open. After a time delay, A, recloses. If the disturbance still remain until the last reclosure of A, by the reclosing relay, it is assumed to be permanent, A, then locking open. After the trouble is corrected, both contactors are reset manually, and normal operation is resumed. If the line clear before the last reclosure of A, this contactor remains closed. Since B, is locked open, it must be reset manually in order to be ready for reclosure in case A, opens later. On voltage failure at any station, any contactors feeding from that station are opened and the signal line energized from the adjacent stations.

over the synchronizing line to start the selectors. The selectors continue to run until the zero position is reached.

As the wiper of the indication bank reaches the associated contact, an impulse of a polarity determined by the breaker auxiliary switch is sent over the indication wire to operate the indication relay in the dispatcher's office. Simultaneously a pick up circuit for the indication auxiliary relay is completed by the wiper of the transfer bank. The indication auxiliary relay picks up and seals itself in through its own contact.

Automatic Hydro-Electric Generating Stations.—In many places throughout the country there are small, undeveloped water power sites, which may be located near each other on the same stream. It is not economical in many cases to use the total head of water of the several sites for the development of one large plant.

To develop each site independently, although a comparatively small initial investment is involved, may not be an economical operating proposition if operators be maintained; but, by the installation of automatic control equipment, which eliminates the operating force, each independent site can be developed into an economical plant.

Control schemes may be roughly divided into two classes:

1. The remotely controlled automatic station, in which the alternator leads run to the main station, where the alternator is synchronized by hand;

2. The entirely automatic station, where the alternator is automatically synchronized into the transmission network.

These control schemes are shown in the accompanying illustrations.

Class 4.—Continued from page 2,801.

If complete automatic resetting be provided, this operation takes place after a brief interval of two to three seconds in all cases. If partial automatic resetting be provided, the operation takes place in two to three seconds at the first failure when A, opens and B, closes. However, upon the second failure when B, opens, there is a time delay (commonly about 15 seconds) before A. recloses.

TEST QUESTIONS

1. *What is a sub-station?*
2. *Upon what does the selection of apparatus and general arrangement of a sub-station depend?*
3. *Give a classification of sub-stations.*
4. *How should a building be constructed for a sub-station?*
5. *Draw a sketch showing general arrangement of machines and apparatus in a sub-station.*
6. *What is an automatic sub-station?*
7. *How is an automatic sub-station usually started?*
8. *What kind of relay gives the stopping indication?*
9. *Give the sequence of the various operations comprising the automatic feature of a sub-station.*
10. *Describe a control system requiring pilot wires for a remotely controlled automatic station.*
11. *Describe a control system which does not require a pilot wire.*
12. *Describe a control system for an entirely automatic station.*
13. *Make a sketch showing a wiring diagram of a typical automatic sub-station.*
14. *Explain the operation of all the automatic devices shown in the sketch of question 13.*
15. *What is a semi-automatic sub-station?*
16. *What methods are used in the operation of a semi-automatic sub-station?*
17. *What automatic devices should be provided for semi-automatic stations. and why?*

18. *Give a comparison between automatic and semi-automatic stations.*
19. *Describe the automatic supervisory equipment.*
20. *Describe the synchronous visual system of supervisory control.*
21. *How does the code visual type work?*
22. *Explain the audible type.*
23. *Describe the operation of the synchronous selector type.*

CHAPTER 91

Power Plant Operation

This chapter relates to the "management" of power plants and this term as broadly used here includes:

1. Selection
2. Location.
3. Erection.
4. Testing.
5. Running.
6. Care.
7. Repair.

The designer of the plant, specifies or "selects" the machines. An erector should install them, but usually this job is left to the man in charge who in most small and medium size plants is the chief engineer, who also must run, care for and repair the machines.

Selection.—To properly *select* a machine so that it will properly harmonize with the conditions under which it is to operate, there are several things to be considered.

1. Type;
2. Capacity;
3. Efficiency;
4. Construction.

The type depends upon the system to be used. Thus, the voltage in most cases is fixed except on transformer systems where a choice of voltage may be had by selecting a transformer to suit.

In alternating current constant pressure transmission circuits, an average voltage of 2,200 volts with step down transformer ratios of $^1/_{10}$ and $^1/_{20}$ is in general use, and is recommended.

For long distance, the following average voltages are recommended

6,000; 11,000; 22,000; 33,000; 44,000; 66,000; 88,000;

and higher, depending on the length of the line and degree of economy desired.

In alternating circuits the standard frequencies are 25 and 60 cycles. These frequencies are already in extensive use and it is recommended to adhere to them as closely as possible.

In fixing the capacity of a machine, ***careful consideration should be given to the conditions of operation both present and future*** in order that the resultant efficiency may be maximum.

Most machines show the best efficiency at or near full load. If the load be always constant, as for instance, a pump forcing water to a given head, it would be a simple matter to specify the proper size of machine, but in nearly all cases, and especially in electrical plants, the load varies widely, not only the daily and hourly fluctuations, but the varying demands depending on the season of the year and growth of the plant's business. All of these conditions tend to complicate the matter, so that intelligent selection of capacity of a machine requires not only calculation but mature judgment, which is only obtained by long experience.

In the application and selection of rotating apparatus the following suggestions as given by the National Electrical Manufacturers Association should be noted.

Proper Selection of Apparatus.—Extreme care should be used in the proper selection of apparatus in order that satisfactory operation and good service will result.

Where the apparatus is subjected to unusual risk, the engineering department of the manufacturer should be consulted; especially where the apparatus is used under the following conditions: 1, exposed to acid fumes; 2,

operated in damp places; 3, where an exceedingly high speed is required; 4, exposed to flour dust; 5, exposed to gritty dust; 6, exposed to steam; 7, operated in poorly ventilated rooms; 8, operated in pits, or where entirely enclosed in boxes; 9, where the maximum operating temperature of the apparatus exceeds 90° C.

Contrary to general belief a synchronous motor will not exert its maximum power factor correction when operating as a synchronous condenser, but will do so when carrying mechanical load at leading power factor.

The characteristic curve shown in fig. 4,807 is from a self-excited synchronous motor. It will be seen from the diagram, that this motor will correct poor power factor conditions and at the same time carry the load of a similarly rated general purpose induction motor.

In general, the amount of power factor correction which a synchronous motor exerts may be varied at will, within the design limits of the motor, by varying its field excitation.

Synchronous motors evidently furnish the ideal means to boost low, lagging power factor, particularly because they may be employed as power motors and at the same time correct poor power factor conditions.

Uses of Single Phase Motors

Type	Power	Speed	Adaptation
Split phase	1/20 to ¼	Constant	Used upon ordinary lighting circuits to drive novelties, sign flashers, washing machines—ordinary torque.
Repulsion-induction	⅛ to 10 *h.p.*	Constant	Used upon ordinary lighting circuits. Applicable to machines requiring high starting torque and where low starting current is desired. Pumps, compressors, etc.

Uses of Polyphase Motors

Type	Power	Speed	Adaptation
Squirrel cage	¼ to 50 *h.p.*	Constant	Light group and individual drives requiring constant speed. No sliding electrical contacts. Used in textile mills, etc., where inflammable dust or gases are encountered.
Wound rotor	½ to 50 *h.p.*	Constant	Used with large group or individual drives requiring high starting torque and low starting current Used on heavy planers, plunger pumps, applications using flywheels, etc.
Wound rotor	½ to 50 *h.p.*	Varying	By means of secondary control, 50% speed variation. Used on pumps, compressors, fans, etc. Same motor as used for constant speed. Varying speed obtained by secondary control.

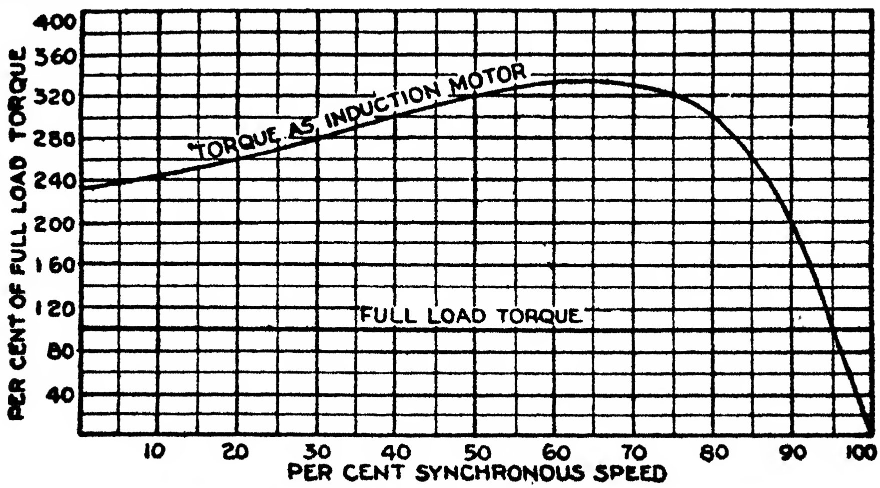


FIG. 4,805.—Speed torque characteristics of Ideal 25 *h.p.*, 440 volt, 3 phase, 1,800 *r.p.m.* general purpose type, self excited synchronous motor. This motor starts as an ordinary squirrel cage motor with torque characteristics similar to the high torque squirrel cage motor. *In general* it is not recommended that the motor be started on full line voltage, Manual starting can be accomplished by means of the ordinary reduced voltage type of compensator used for starting induction motors. For remote control the automatic compensator may be used with push button stations. After the motor attains approximate synchronous speed it automatically becomes a self-excited synchronous motor. Best results are usually obtained with approximately 90% leading power factor at full load.

Synchronous Motors for Power and Power Factor Correction.—It may be stated that the crowning feature of synchronous motors is their two fold use. They deliver, at constant speed, mechanical power and simultaneously improve bad power factor conditions. Though ordered as power motors to operate at unity power factor only, still in addition they may be called upon to exert their beneficial tendency on systems where low power factor prevails.

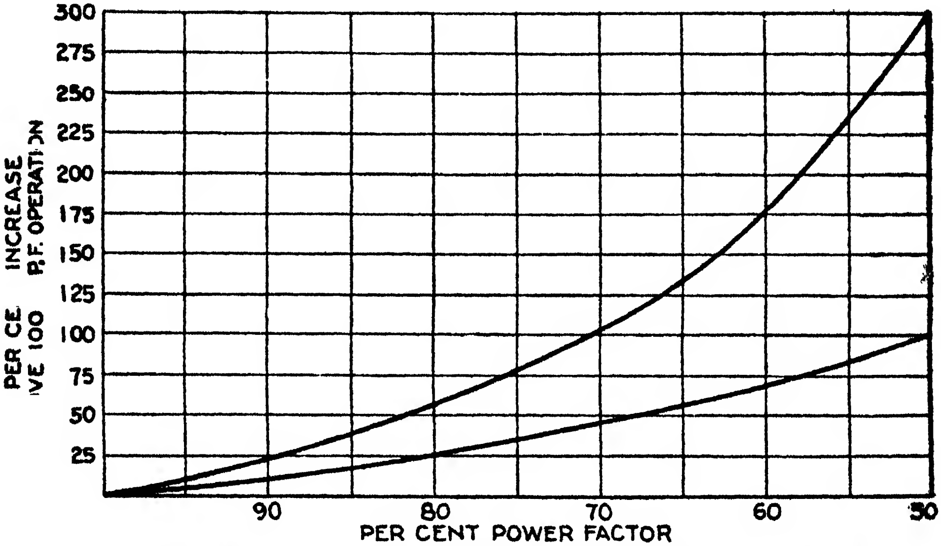


FIG. 4,806.—Curves showing losses for various power factors. Owing to the undue increase in power and line equipment necessitated by consumers operating at low, lagging power factor, it is obvious why central stations and power companies have taken a very unfriendly attitude toward consumers who operate at low, lagging power factor, and the increased tendency prevails to penalize such consumers by imposing a heavier power rate. At the present time some power companies are giving a bonus or rebate to consumers who use synchronous motors and therefore operate at a high power factor, because as is apparent from the above, this operation has a direct bearing on the economy of the central station.

Any electrical system furnishing power supplies current at a certain rated voltage, and the power consumed is proportional to the product of both. A system supplying alternating current is maintaining current at a certain power factor. This means that only part of the current is producing power while the balance is furnished as wattless current, which must be maintained for the operation of certain motors and equipment feeding from the supply. Only the watt current produces useful work.

The wattless current on the other hand requires the same attention and equipment in alternators, transformers, lines, etc., as does the watt current and produces the same losses in this equipment as does the watt or power current. The curves in fig. 4,806 show these losses increase as the power factor falls off, which actually means very much lowered efficiency both inside and outside the consumer's plant. In other words, not only the user but also the central station supplying the power must increase the equipment of alternators, transformers, lines, feeders, etc., to take care of these losses.

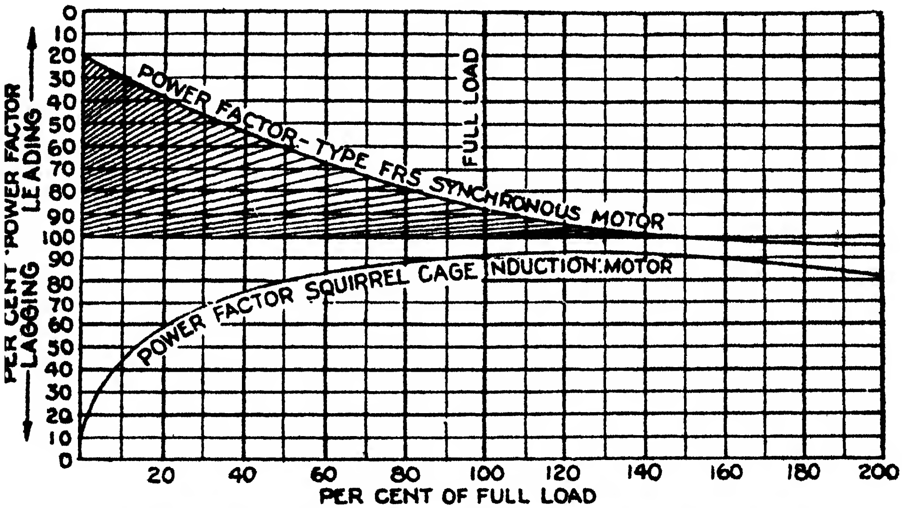


FIG. 4,807.—Power factor curves of Ideal self-excited synchronous motor and squirrel cage motor both rated at .25 *h.p.*, 440 volts, 3 phase, 60 cycle, 1,800 *s.r.p.m.* ***It should be noted*** that with the windings provided for 90% leading power factor at full load, the power factor at 80% load is 80% *p.f.* leading at 60% load, 65% *p.f.* leading, etc. When the motor is loaded to approximately 150% of full load the power factor is unity. The shaded area represents the leading *kva.* that this motor is capable of developing over the load range shown. During the starting period no excessive currents are carried in the auxiliary direct current winding of the armature; therefore, there is no possibility of damaging this winding. All heavy secondary starting currents are localized in the squirrel cage winding of the pole faces. No secondary resistance is required as the motor starts as an ordinary squirrel cage induction motor. As soon as synchronous operation is attained the pull out or break down torque is approximately 200 to 225% of full load torque, depending upon the field adjustment. This type synchronous motor is adapted for driving all kinds of machinery which require relatively high speed motors such as centrifugal pumps, line shafts, etc. Sufficient starting torque is available to start any load which a normal squirrel cage induction motor will start.

Application of "General Purpose" Motors.—All performance guarantees given relate to the normal 40° C. rating and remain

unchanged when the permissible loading indicated by the service factor is utilized.

Performance guarantees of momentary overloads, starting and pull out torque are all given as a percentage of the normal 40° C. rating, there being no change in the basic design of the motor or the pounds starting and pull out torque by the use of the conventional service factor.

In general, slight differences in efficiencies and power factors may be expected at the permissible loading indicated by the service factor.

The normal 40° C. general purpose motor is designed for continuous duty, 100% loading, an ambient temperature not exceeding 40°C., an allowable variation from rated frequency of 5% or a combined variation of voltage and frequency not exceeding 10%. When authorized by the manufacturer, such a motor operated at its rated voltage (and rated frequency in the case of alternating current motors) will carry continuously 1.15 times its rated load. This factor of 1.15 shall be known as a service factor.

Usual Service Conditions for General Purpose Motors.—General purpose motors are designed to give successful operation at rated load under the following service conditions defined as usual:

1. An ambient temperature not exceeding 40° C.
2. A variation in voltage of not more than 10% above or below the name plate rating.
3. A variation in frequency of not more than 5% above or below the name plate rating.
4. A combined variation of voltage and frequency of not more than 10% above or below the name plate rating, providing the frequency do not exceed 5% variation.
5. An altitude not exceeding 1,000 meters (3,300 ft.).
6. Location or atmosphere conditions as to dust, moisture or fumes which will not seriously interfere with the ventilation of the motor.
7. Solid mounting and all belt drives and gearing in accordance with rules.

In general, the service conditions to which such motors are subjected are uncontrolled and not subject to exact determination, and the basis of rating chosen provides a factor of safety of 10° C. temperature rise.

Effects of Variation of Voltage and Frequency upon the Performance of Induction Motors.—Induction motors are at times

operated on circuits of different voltage or frequency from that for which the motors are rated. Under such conditions, the performance of the motor will vary from the standard rating. The following is a brief statement of some operating results caused by small variations of voltage and frequency, and is indicative of the general character of changes produced by such variations in operating conditions:

1. Voltage variations of 10% on power circuits are allowed in most commission rules. However, changing the voltage applied to an induction motor has the effect of changing its proper rating as far as power factor and efficiency are concerned, in proportion to the square of the applied voltage.

Thus a 5 *h.p.* motor, operated at 10% above the rated voltage, would have characteristics proper for a 6 *h.p.* motor (6.05 *h.p.* to be exact) and at 10% below the rated voltage, those of a 4 *h.p.* motor (more exactly 4.05 *h.p.*). It is of course obvious that if the rating of a motor were greatly increased in this way, the safe heating would frequently be exceeded.

2. In a motor of normal characteristics at full rated horse power load, a 10% increase of voltage above that given on the name plate would usually result in a slight improvement in efficiency and a decided lowering in power factor. A 10% decrease of voltage below that given on the name plate would usually give a slight decrease of efficiency and an increase in power factor.

3. The starting and pull out torque will be proportional to the square of the voltage applied. With a 10% increase or decrease in voltage from that given on the name plate, the heating at rated horse power load will not exceed safe limits when operating in ambient temperatures of 40° C., or less, although the usual guaranteed rise may be exceeded.

4. An increase of 10% in voltage will result in a decrease of slip of about 17% while a reduction of 10% will increase the slip about 21%.

5. Higher than rated frequency usually improves the power factor, but decreases starting torque, and increases the speed, friction and windage. At lower than rated frequency, the speed is, of course, decreased; starting torque is increased; and power factor slightly decreased. For certain kinds of motor load, such as in textile mills, close frequency regulation is essential.

6. If variations in both voltage and frequency occur simultaneously, the effects will be superimposed. Thus if the voltage be high and the frequency low, the starting torque will be very greatly increased, but the power factor will be decreased and the temperature rise increased with normal load.

The foregoing facts apply particularly to general purpose motors. They may not always be true in connection with special motors built for a particular purpose, or as applied to very small motors.

Definitions

Ambient temperature.—The temperature of the air or water which, coming into contact with the heated parts of a machine, carries off their heat. The standard ambient temperature of reference when the cooling medium is air, shall be 40° C.

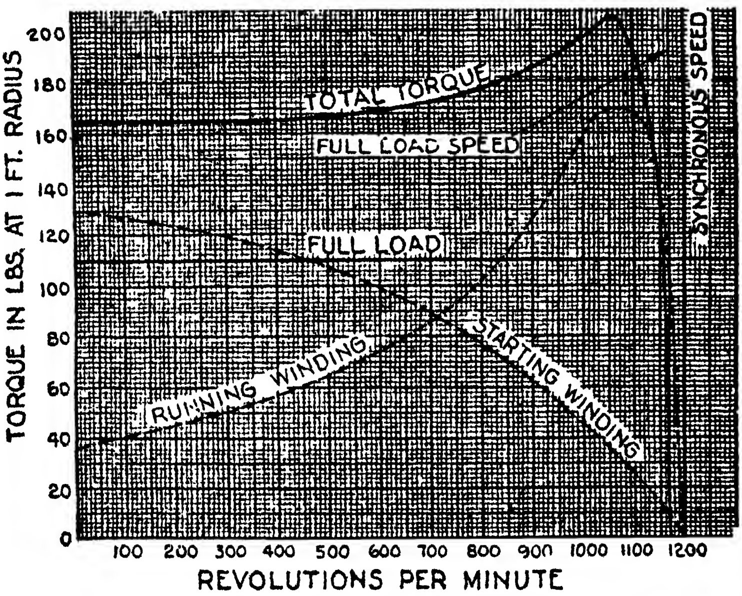


FIG. 4,808.—Torque characteristics of Ideal 25 *h.p.* double squirrel cage induction motor. The gain in efficiency of this type of motor over the standard squirrel cage motor is due to the fact that the inner squirrel cage winding is made of very low resistance material and the rotor loss at full speed, full load reduces to an almost negligible value. In the old type of motor it was necessary to have considerable rotor resistance and therefore heavy rotor losses in order to gain sufficient starting torque.

Brush dimensions.—The *length* of a brush is the maximum dimension in the direction in which the brush feeds to the commutator or collector ring. The *thickness* of a brush is the dimension at right angles to the length in the direction of rotation. The *width* of a brush is the dimension at right angles to the length and to the direction of rotation.

Conducting parts.—Those which are designed to carry current or which are conductively connected therewith.

Connection diagram.—A diagram showing the relations and connections of devices and apparatus of a circuit or group of circuits.

Contact.—A surface common to two conducting parts, united by pressure for the purpose of carrying current.

Continuous duty.—A requirement of service which demands operation at substantially constant load for an unlimited period.

Enclosed machine.—A machine which is so completely enclosed by integral or auxiliary covers as to practically prevent the circulation of air through its interior. Such a machine is not necessarily air tight.

Grounded parts.—Those parts of apparatus connected to ground or which may be considered to have the same potential as the earth.

Insulating bushing.—A bushing which insulates a through conductor from the material through which the conductor passes.

Intermittent duty.—A requirement of operation or service consisting of alternate periods of load and rest so apportioned and regulated that the temperature rise at no time exceeds that specified for the particular class of apparatus under consideration.

Leads.—Insulated conductors, flexible or solid, furnished connected to a device or piece of apparatus.

Open machine.—A machine of either the pedestal bearing or end bracket type, with no restriction as to ventilation other than that imposed by good mechanical construction.

Periodic duty.—A requirement of service which demands operation for alternate periods of load and rest in which the load conditions are well defined and recurrent as to magnitude, duration and character.

Protected machine.—A machine in which the armature, field coils and other live parts are protected mechanically from accidental or careless contact, while free ventilation is not materially obstructed.

Rating.—A rating of a machine, apparatus or device, is an arbitrary designation of an operating limit.

Semi-enclosed machine.—A machine in which the ventilating openings in the frame are protected with wire screen, expanded metal, or perforated covers, the openings in which must not exceed ½ sq. in. in area and must be of such shape as not to permit the passage of a rod larger than ½ in. in diameter.

Varying duty.—A requirement of operation or service in which the apparatus is called upon to run at loads, and for periods of time, which may be subject to wide variation, but which are in no case sufficient to cause the maximum temperature rating to be exceeded. In no instance shall the no load losses be sufficient to cause the maximum temperature rating to be exceeded in any part under no load continuous operation.

Weatherproof apparatus.—Apparatus so constructed or protected that exposure to the weather will not interfere with its successful operation.

Connections and Markings of Terminals.—The purpose of applying markings to the terminals of electric power apparatus according to a standard is to aid in making up connections to other parts of the electric power system and to avoid improper connections which may result in unsatisfactory operation or damage.

The markings are placed on, or directly adjacent to terminals to which connections must be made from outside circuits or from auxiliary devices which must be disconnected for shipment. They are not intended to be used for internal machine connections.

The markings consist of a capital letter of the alphabet followed by a subscript numeral (Arabic). The letter indicates the character or function of the winding which is brought to the terminal.

A terminal letter followed by the subscript numeral "0" designates a neutral connection. Thus T_0 would be applied to the terminal on the connection from the neutral point of a stator winding.

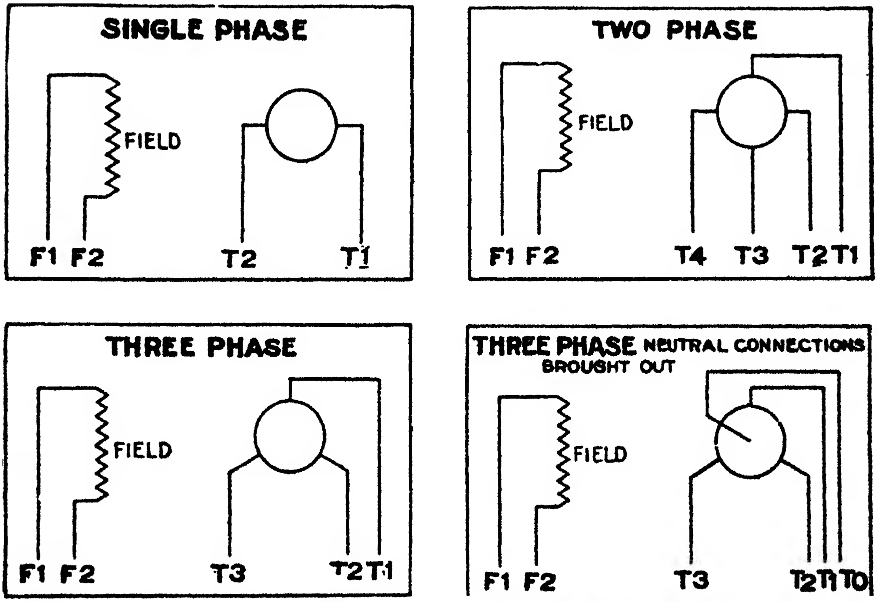
The subscript numerals 1, 2, 3, etc., indicate the order of the phase succession for standard direction of rotation. This standard direction of rotation for alternators and synchronous motors is clockwise when facing the end of the machine opposite the drive.

It is customary to connect up the coil windings and place the collector rings on this end.

In a synchronous converter the sequence of the subscript numerals 1, 2, 3 applied to the collector ring leads M_1, M_2, M_3 indicates that when the

collector ring leads are connected to correspondingly numbered terminals of a three phase alternator, the standard rotation of the alternator (clockwise facing the end opposite the drive) will cause the direction of rotation, which is clockwise when viewing the direct current or commutator end.

On single phase transformers the subscript numerals indicate the polarity relation between terminals on primary and on secondary windings. Thus, during that part of the alternating current cycle when high tension terminal H_1, is positive (+) with respect to H_2, in the same part of the cycle the low tension terminal X_1, is positive with respect to X_2. The idea is further carried out in single phase transformers having tapped windings, by so applying



Figs. 4,809 to 4,812.—Connections and terminal markings for alternators and synchronous motors according to N. E. M. A. standard. Fig. 4,809, single phase; fig. 4,810, two phase; fig. 4,811, three phase; fig. 4,812, three phase with neutral connections brought out. Standard phase and rotor rotation clockwise, facing the end opposite the drive.

to the taps the subscript numerals 1, 2, 3, 4, 5, etc., that the voltage gradient follows the sequence of the subscript numerals. In the case of polyphase transformers, the terminal subscript numerals are so applied that if the phase sequence of voltage on the high voltage side is in the time order H_1, H_2, H_3, etc., it is in the time order X_1, X_2, X_3, etc., on the voltage side, and also in the time order Y_1, Y_2, Y_3, etc., if there be a tertiary winding.

Rotor and Phase Rotation.—Alternators driven counter

clockwise (clockwise is standard) will alternate without change in connections, but the phases will follow the sequence of 3, 2, 1, instead of sequence, 1, 2, 3, etc. Synchronous motors, synchronous condensers, induction motors and synchronous converters may be operated with reversed rotation by so transposing connections that the phase sequence of the polyphase supply is applied to the terminals in reversed order for example 3, 2, 1.

With synchronous converters, the practice of alternating current starting eliminates residual magnetism as the factor determining the direct current polarity. Proper polarity for connection to other apparatus is, therefore, secured either by separate excitation of the field, or by special manipulation of a switch which permits the converter to reverse its direct current polarity, thus correcting a start with wrong polarity.

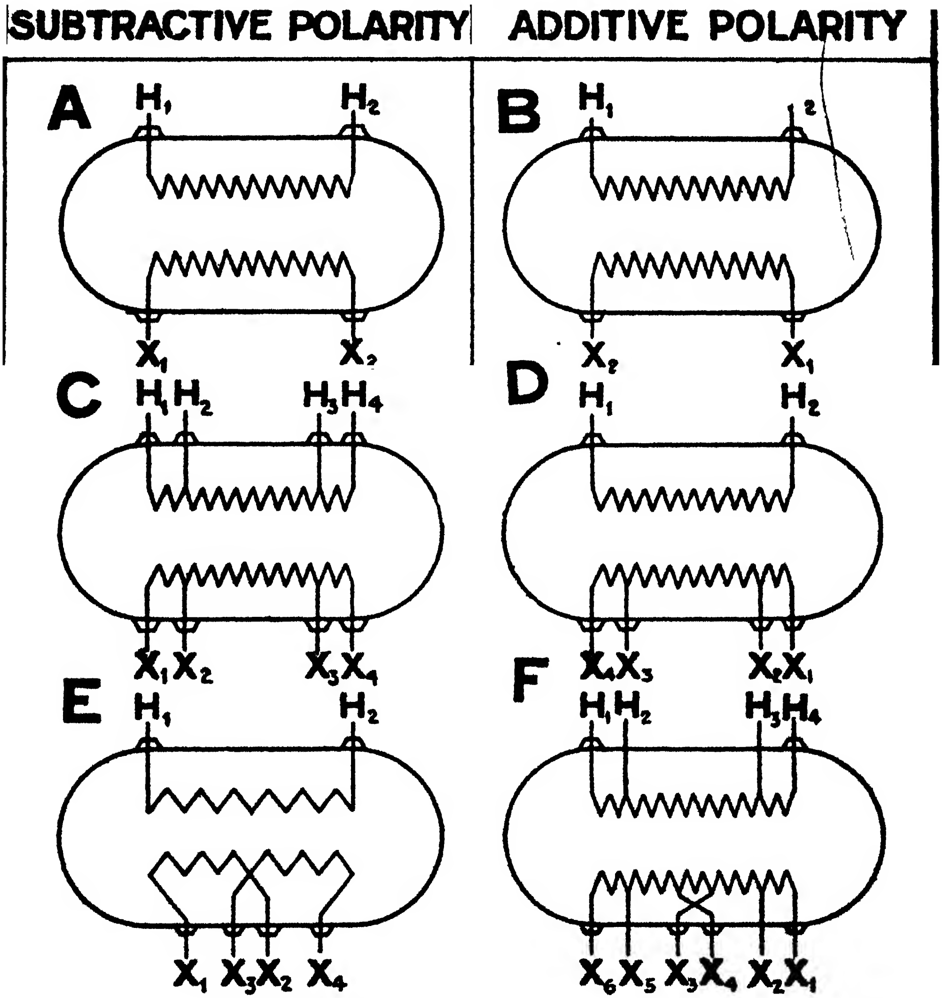
If a synchronous converter is to be operated with reversed direction of rotation (counter clockwise viewing the machine from the commutator end) it is necessary to make a transposition of the armature leads, or a transposition of the field leads, besides transposing the alternating current terminal connections as in the case of a dynamo.

Rating of Alternators.—These machines are rated at the load they are capable of carrying continuously without exceeding their temperature guarantees. The rating shall be expressed in *kva.* available at the terminals at .8 power factor. The corresponding kilowatts should also be stated.

Standard voltages are 240, 480, 600 and 2,400 and standard frequencies are 25 and 60 cycles per second. The standard excitation voltage for field windings shall be 125 volts *d.c.* Standard general purpose alternators shall operate successfully at power factors at least as low as .8.

Voltage Taps of Transformers.—Standard distribution transformers, sizes 200 *kva.* and smaller, wound for voltages below the 6,600 volt class are not provided with taps.

NOTE.—*Dynamos* with connections properly made up for standard rotation (clockwise) will not function if driven counter clockwise as any small current delivered by the armature tends to demagnetize the fields and thus prevents the armature delivering current. If the conditions call for reversed rotation, connections should be made up with either the armature leads transposed or the field leads transposed.

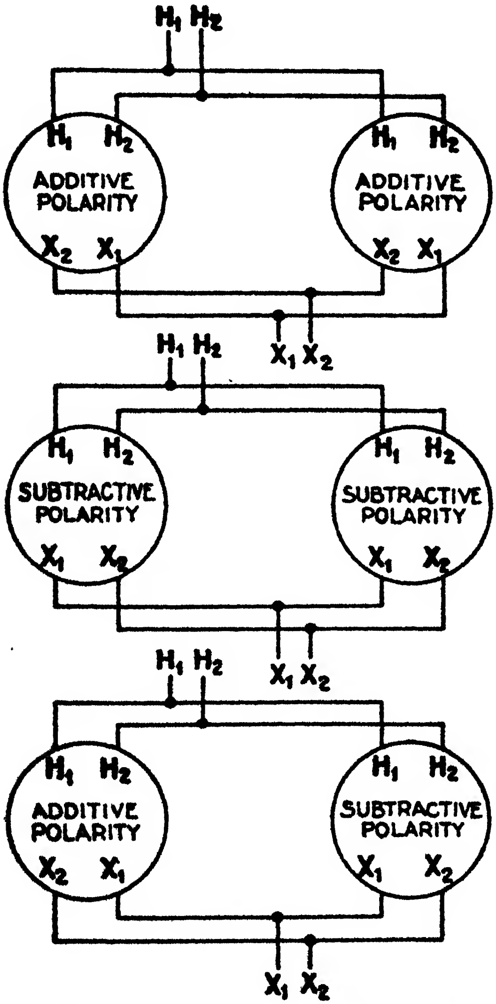


FIGS. 4,813 to 4,818.—*Lead markings; single phase* transformers. A and B, simple high and low voltage windings without taps; C and D, simple high and low voltage windings, with taps; E, series parallel low voltage winding without taps; F, series parallel low voltage winding, with taps. The leads are marked.

NOTE.—*Transformer name plate marking.*—All transformer name plates include as a minimum the following information: 1, serial number; 2, type; 3, number of phases; 4, kva and time rating; 5, voltage rating; 6, frequency; 7, temperature rise; 8, polarity (for single phase transformers)

Standard single phase distribution transformers 200 *kva.* and smaller of the 6,600 volt class or for higher voltages are provided with taps in the high voltage winding for approximately 5 and 10% voltage variation.

Standard single phase distribution transformers, sizes above 200 *kva.* are provided with taps in the high voltage winding for 10% voltage variation in steps of approximately 2½%.



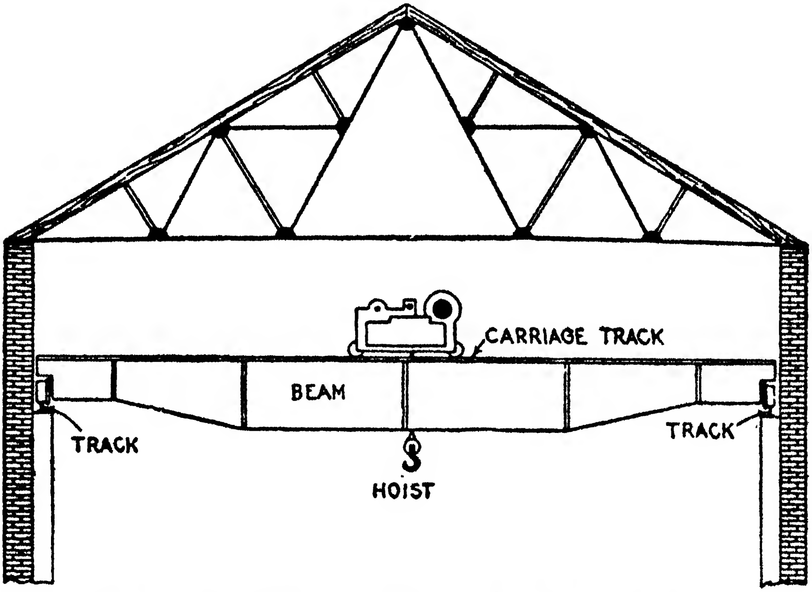
Standard three phase distribution transformers above 200 *kva.* wound for voltages below the 6,600 volt class, are provided with taps in the high voltage winding for approximately 5 and 10 per cent voltage variation.

Standard three distribution transformers of the 6,600 volt class and above are provided with taps in the high voltage winding for approximately 5 and 10 per cent voltage variation.

The low voltage windings of distribution transformers of standard voltage ratings are not provided with taps.

FIG. 4,819.—Connections for single phase transformers in parallel illustrating hook up for of additive polarity, subtractive polarity, and additive and subtractive polarity.

Installation.—The placement of machines and apparatus in an electrical station is a task which increases in difficulty with the size of the plant. When the parts are small and comparatively light they may readily be placed in position, either by hand, by erecting temporary supports which may be moved from place to place as desired, or by rolling the parts along on the floor upon pieces of iron pipe. If, however, the parts be



ᐟIG. 4,820.—Cross section of electrical station showing small traveling crane.

arge and heavy, a traveling crane such as shown in fig. 4,821, ›ecomes necessary.

Care should be taken not to injure the bearings and shafts, he joints in magnetic circuits such as those between frame and ole pieces, and the windings on the field and armature.

The insulations of the windings are perhaps the most vital parts of a generator, and the most readily injured. The prick of a pin or tack, a bruise, or a bending of the wires by resting their weight upon them or by their coming in contact with some hard substance, will often render a field coil or an armature useless.

Owing to its costly construction, it is advisable when transporting armatures by means of cranes to use a wooden spreader, to prevent the supporting rope bruising the winding.

When the armature cannot be placed at once in its final position, it may be laid temporarily upon the floor, if a sheet of cardboard or cloth be placed underneath the armature as a

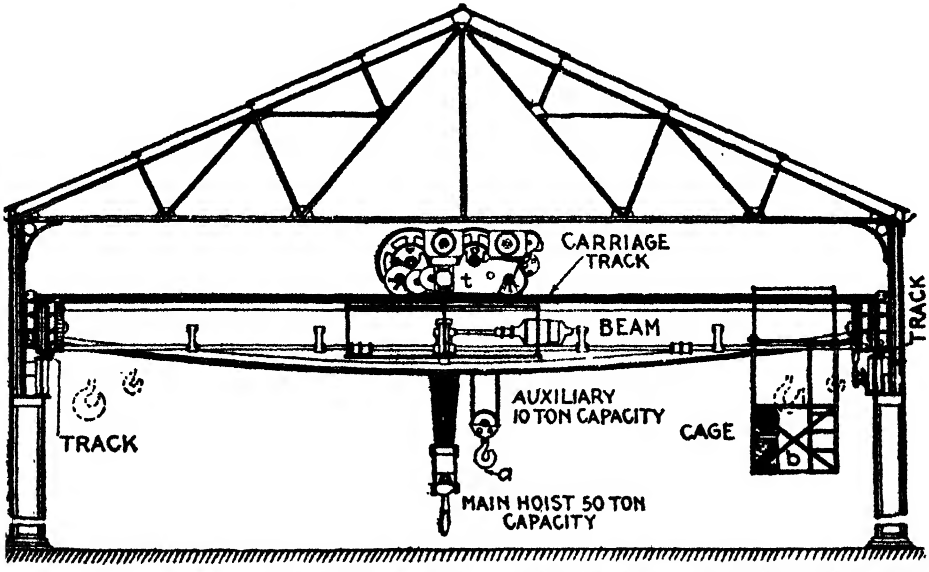


FIG. 4,821.—Cross section of electrical station showing a traveling crane for the installation or removal of large and heavy machine parts. The track upon which the crane moves is not supported by the walls of the building, but rests upon beams specially provided for the purpose. In addition to the horizontal motion thus obtained, another horizontal motion at right angles to the former is afforded by means of the carriage which, being also mounted on wheels, runs upon a track on the top of the beam. In the larger sizes of electric traveling crane, a cage is attached to the beam for the operator, who, by means of three controllers mounted in the cage, can move a load on either the main or auxiliary hoist in any direction.

protection for the windings; in case the armature is not to be used for some time, it is better practice to place it in a horizontal position on two wooden supports near the shaft ends.

For belt driven machines the base should be provided with V ways and adjusting screws for moving the machine horizontally to take up slack in the belt, as shown in fig. 4,822.

Owing to the normal tension on the belt, there is a moment exerted equal in amount to the distance from the center of gravity of the machine to the center of the belt, multiplied by the effective pull on the belt. This force tends to turn the machine about its center of gravity. By placing the screws as shown, any turning moment, as just mentioned, is prevented.

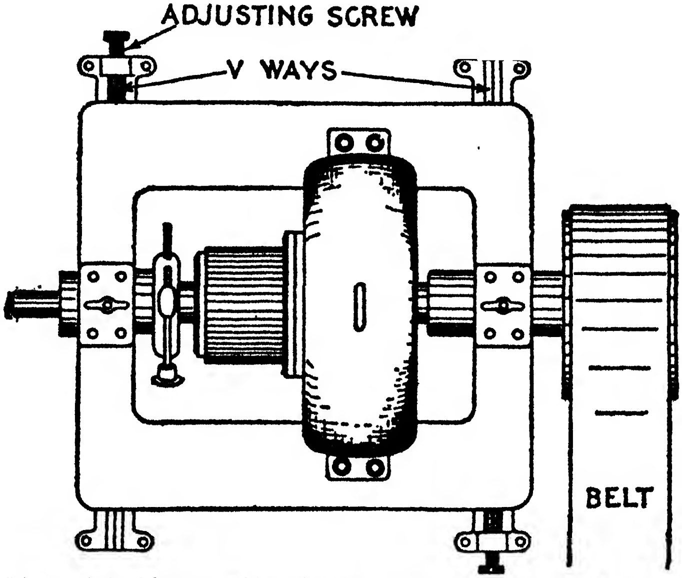


FIG. 4,822.—Plan of belt driven machine showing V ways and adjusting screws for moving the machine forward from the engine or counter shaft to take up slack in the belt.

How to Use Belt Speed Table.—In order to facilitate the calculation of belt speed in feet per minute, when the corresponding motor speed and pulley diameter is known, the table on the following page will be of assistance.

Example.—Assume the full load speed of a motor, having a pulley whose diameter is 11 inches, to be 1,750 *r.p.m.* what is the corresponding belt speed?

Solution.—On the 1,750 *r.p.m.* line in the table read the figure corresponding to a pulley diameter of 11 ins. which is 5,040. In other words, when an 11 inch diameter pulley rotates at 1,750 revolutions per minute, a belt on this pulley travels at a speed of 5,040 feet per minute. In a similar manner belt speed of motors whose *r.p.m.* and pulley diameters are given in the table. may be read directly without calculation.

Table I—Belt Speeds

Full-Load Speed of Motor in Rpm	Pulley Diameters in Inches — Belt Speed in Feet per Minute										
	3½	4	4½	5	5½	6	7	8	9	10	11
1750	1605	1835	2060	2290	2520	2750	3205	3670	4125	4580	5040
1450	1330	1520	1710	1900	2090	2275	2660	3040	3420	3800	4170
1150	1055	1205	1355	1505	1655	1810	2110	2410	2710	3010	3315
860	790	900	1015	1130	1240	1350	1575	1800	2030	2255	2480
690	....	725	815	905	995	1085	1265	1445	1625	1810	1990
575	....	....	680	755	830	905	1055	1205	1355	1505	1655

Full-Load Speed of Motor in Rpm	Pulley Diameters in Inches — Belt Speed in Feet per Minute										
	12	13	14	15	16	17	18	19	20	21	22
1450	4560	4930									
1150	3615	3915	4220	4520	4820	5120					
860	2705	2930	3160	3380	3610	3835	4060	4280	4510	4740	4960
690	2170	2350	2530	2710	2890	3075	3250	3435	3615	3800	3980
575	1805	1955	2105	2260	2410	2560	2710	2860	3010	3160	3310

Full-Load Speed of Motor in Rpm	Pulley Diameters in Inches — Belt Speed in Feet per Minute										
	23	24	25	26	27	28	29	30	31	32	33
690	4160	4340	4520	4700	4880	5060					
575	3460	3610	3760	3915	4060	4210	4360	4515	4665	4815	4965

The above table is based on the formula:

Belt speed in feet per minute =

$$\frac{3.1416 \times \text{pulley diameter in inches} \times \text{rpm}}{12}$$

The length of belts is found by various methods such as:

1. Direct measurement
2. Calculation
3. Scale

Direct Measurement.—This is the simplest and undoubtedly the safest method as well. A steel tape carefully adjusted over the pulley crowns will give the length of belting required. To this should be added a reasonable amount of material for jointing as required in each individual case.

Calculation.—The calculation method is useful in locations where a direct measurement cannot readily be obtained. In many instances it may be necessary to obtain the length of belting from *blue prints* where only shaft center distances and pulley diameters are given. This as a matter of fact, is most often the case especially on new constructions, where the entire plant machinery is laid out on drawings according to a *carefully engineered* plan.

In belting up such a plant it is imperative that the millwright has the knowledge necessary to intelligently cut and assemble belts without undue waste of material.

Generally, belts may be divided into two groups:

1. Belts driving their connecting pulleys in the *same* direction or ***Open Belts.***

2. Belts driving their connecting pulleys in the *opposite* direction or ***Crossed Belts.***

Formula for Length of Crossed Belts.—With reference to fig. 1 the exact length (L) of a crossed belt may be written

$$L = \left(\pi + \frac{\pi}{90} \times \phi\right)(R + r) + 2 \times C \cos \phi. \quad (1)$$

Where R = radius of the larger pulley

r = radius of the smaller pulley

C = distance between shaft centers

ϕ = angle whose sine is $\frac{R+r}{C}$

Although this formula is found in most handbooks in one form or another, it should perhaps not be used unless the reader clearly understands its derivation.

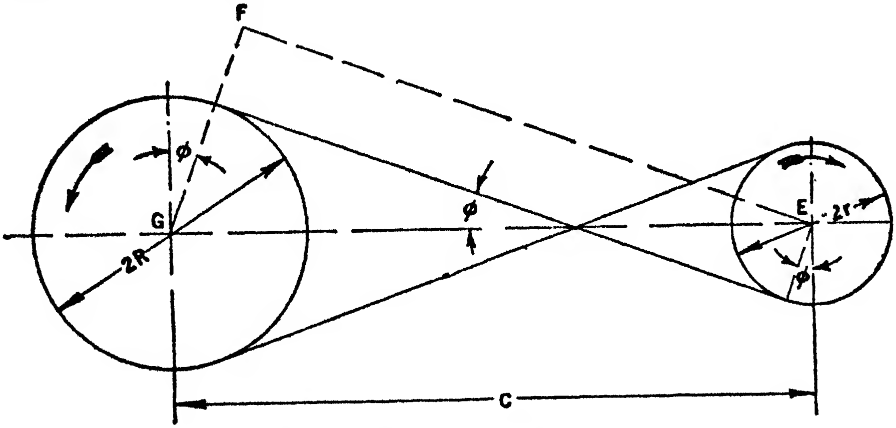


FIG. 1.—Diagram for calculation of length of a crossed belt.

The length of the belt with reference to the illustration is simply found by adding up the various elements involved. Thus, starting with the larger of the two pulleys, the length of pulley arc indicated by angle ϕ is $\frac{2\pi R}{360} \times \phi$, but inasmuch as there are two such elements their combined lengths are $\frac{4\pi R}{360} \times \phi$.

In a similar manner the arcs on the smaller pulley are obtained as $\frac{4\pi r}{360} \times \phi$.

To the four arcs should finally be added twice the distance EF, and half the circumference of each pulley.

The length (L) of the belt is hence

$$L=\frac{\pi R\phi}{90}+\frac{\pi r\phi}{90}+\pi R+\pi r+2\,C\cos\phi,\ \text{which}$$

after re-arrangement of terms becomes

$$L=\left(\pi+\frac{\pi\phi}{90}\right)\left(R+r\right)+2\,C\cos\phi \text{ as previously written.}$$

If the radius of the pulleys be substituted for their diameters respectively the formula becomes

$$L=\left(\pi+\frac{\pi\phi}{90}\right)\left(\frac{D+d}{2}\right)+2\,C\cos\phi\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

A somewhat simpler formula giving the approximate length (L) of a crossed belt is—

$$L=\frac{\pi}{2}\left(D+d\right)+2\sqrt{C^2+\left(\frac{D+d}{2}\right)^2}\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Example.—If in a *cross* belt transmission drive the pulley shaft distance be 10 ft. and the pulley diameters are 54 ins. and 9 ins. what length of belt should be used?

Solution.—Inserting values in formula (2) and remembering that the angle ϕ fig. 1 is that angle whose sine is $\frac{R+r}{C}$, then $\sin\phi=\frac{31.5}{120}=0.2625$· from a table of natural sines and cosines the corresponding angle ϕ is 15.2 degrees.

Substituting numerical values,

$$L=\left(3.14+0.035\times15.2\right)\left(\frac{4.50+0.75}{2}\right)+2\times10\times0.9650$$

from which $L=28.93$ ft., say 29 ft.

Formula for Length of Open Belts.—Contrary to the case of a crossed belt, the exact length of an open belt is somewhat difficult to obtain; however, an approximate formula in which the errors do not exceed practical limitations is derived from fig. 2.

If the length between the pulley centers (C) be given, and the pulley diameter be respectively (D) and (d), then the length of the belt is—

$$L=\frac{\pi D}{2}+\frac{\pi d}{2}+2\sqrt{C^2+\left(\frac{D-d}{2}\right)^2} \quad \text{or}$$

$$L=\frac{\pi}{2}\left(D+d\right)+2\sqrt{C^2+\left(\frac{D-d}{2}\right)^2} \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

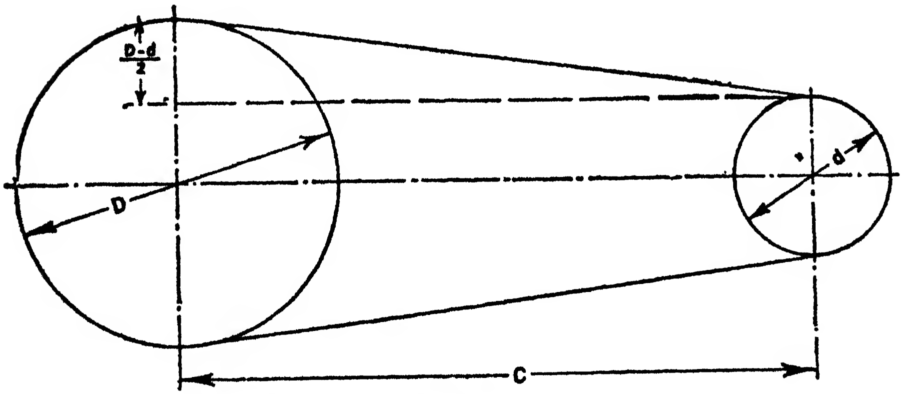


Fig. 2.—Diagram for calculation of length of an open belt.

Example.—The shaft center distance between two pulleys in an *open* belt drive is 12 ft. If the pulley diameters are 4 ft. and 1 ft. respectively what is the length of belting required?

Solution.—Substituting values in formula (4)

$$L=\frac{\pi}{2}(4+1)+2\sqrt{12^2+1.5^2} \quad \text{or}$$

$$L=\frac{5\pi}{2}+2\sqrt{146.25}=7.854+2\times12.1=32.054 \text{ ft., say } 32 \text{ ft.}$$

Scale Method.—This method consists of laying out the pulley set at their proper distance apart, either full size or in a suitable scale and measure the length of the side of the belt, assuming the belt to envelop one half the circumference of each pulley, and to add to this, one half the circumference of each pulley.

Length of Belts for Equal Size Pulleys.—When the pulleys are of the same diameter, or nearly so, the length of an *open belt* may be obtained as follows:

Add together in inches the diameter of the two pulleys, then divide the result by 2; now, multiply the quotient by (π) or 3.14. Finally add in inches twice the distance between the pulley centers.

If this be written algebraically, we have

$$L = \frac{(D+d)\pi}{2} + 2\,C. \qquad (5)$$

where

L = Length of belt in inches

D = Diameter of the larger pulley in inches

d = Diameter of the smaller pulley in inches

C = Distance between pulley shaft centers in inches.

Example.—How many feet of belting is necessary to connect two pulleys of 28 and 21 inches diameter respectively, when their shaft center distance is 18 ft. 6 ins.?

Solution.—By employing the previously enumerated rule or formula,

$$L = \frac{(28+21)}{2}3.14 + 2\times12\times18.5 = 520.93 \text{ inches or 43 ft. 5 ins.}$$

Belt Tension and Horse Power.—With reference to fig. 3 the power transmitted from one pulley to the other is directly proportional to the difference in tension (T_1-T_2) and the speed of the belt.

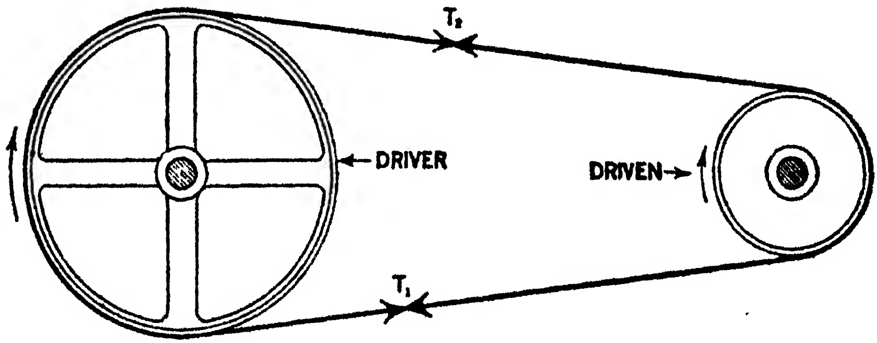


FIG. 3.—Illustrating belt tension in typical belt drive.

If (T_1-T_2) be measured in pounds and the belt speed (V) in ft. per minute, the horse power (h.p.) transmitted may be written:

$$H.P. = \frac{(T_1 - T_2)V}{33{,}000} \quad \ldots\ldots (1)$$

but since the speed $V = \pi \times D \times N$ it follows that

$$H.P. = \frac{(T_1 - T_2)\pi \times D \times N}{33{,}000} \quad \ldots\ldots (2)$$

where

D = pulley diameter in feet

N = revolution per min. of pulley shaft

$\pi = 3.1416$

Example.—The full load speed of a motor having a 9 in. diameter pulley is 850 *r.p.m.* If the high and low tension pulls are 150 lbs. and 30 lbs. what is the horse power transmitted to the belt?

Solution.—Substituting numerical values in the formula the horse power—

$$\text{H.P.} = \frac{(150-30)\pi \times 9/12 \times 850}{33,000} = 7.28, \text{ say } 7\tfrac{1}{4} \text{ H.P.}$$

The customary method of expressing the amount of slack side tension (T_2) necessary for a successful drive is in the form of a ratio commonly called the *tension ratio.* This ratio is written T_1/T_2 and usually varies over rather large limits, depending upon pulley diameter ratios, center distances, pulley gripping quality, type of belting employed, etc.

Millwright's Rules for Determination of Belt Sizes.—For a given condition the minimum belt width is determined by the horse power to be transmitted, and the speed of the belt.

The millwright's rules are as follows:

Rule I.—A single belt 1 in. wide, running at 800 ft. per min. will deliver approximately 1 horse power (up to about 4000 *r.p.m.*).

Rule II.—A double belt 1 in. wide, running at 500 ft. per min. will deliver approximately 1 horse power (up to about 4000 *r.p.m.*).

These rules will give wide margins of safety in ordinary power transmission when the speed of the belt does not exceed 4000 ft. per min. Above this speed the centrifugal effects due to the belt weight begin to be rather appreciable and should therefore be included.

For heavy transmission and speed exceeding 4000 ft. per min. the above rules should be checked with the manufacturers' recommendation.

As it is more convenient for calculation purposes to express rules in algebraic forms, thus for single belts,

$$Bw = \frac{\text{H.P.} \times 800}{V} \quad \text{(3)}$$

where,

$$Bw = \text{Belt width in inches}$$
$$V = \text{Belt speed in ft. per minute}$$
$$H.P. = \text{Horse power transmitted}$$

Similarly for double belts,

$$Bw = \frac{H.P. \times 500}{} \qquad (4)$$

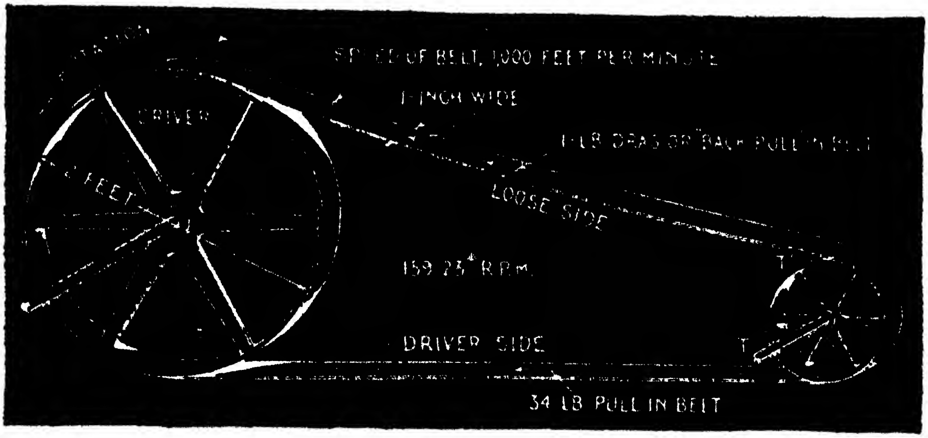


FIG. 4.—Illustrates a belt transmitting one horse power. In the figure the tension in the tight side of the belt is 34 pounds and in the loose side 1 pound. The driving force is therefore = 34-1 = 33 lbs. Since the belt is traveling at a velocity of 1,000 ft. per min. the power transmitted = 33 lbs. × 1,000 ft. = 33,000 pound-feet = 1 horse power.

Operation of Alternators.—The operation of an alternator when run singly differs but little from that of a dynamo.

As to the preliminaries, the exciter must first be started. This is done in the same way as for any shunt dynamo. At first only a small current should be sent through the field winding of the alternator; then, if the exciter operate satisfactorily and the field magnetism of the operator show up well, the load may gradually be thrown on until the normal current is carried, the same method being followed as in the case of a dynamo.

On loading an alternator, a noticeable drop in voltage occurs across its terminals. This drop in voltage is caused in part by

the demagnetization of the field magnets due to the armature current, and so depends in a measure upon the position and form of the pole pieces as well as upon those of the teeth in the armature core. The resistance of the armature winding also causes a drop in voltage under an increase of load.

Another cause which may be mentioned is the inductance of the armature winding, which is in turn due to the positions of the armature coils with respect to each other and also with respect to the field magnets.

Alternators in Parallel.—When the load on a station increases beyond that which can conveniently be carried by one alternator, it becomes necessary to connect other alternators in

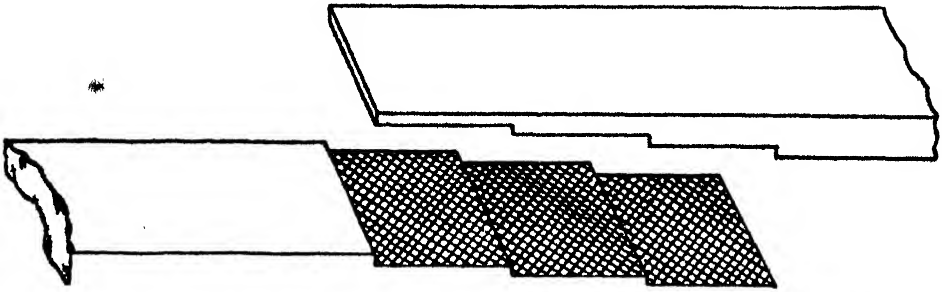


FIG. 4,834—Step splice for a rubber belt. For belts larger than 12 inches the step splice here shown is recommended. A lap joint is formed having three steps, three or four inches being allowed for each ply of duck. Care should be taken not to cut into the ply below when forming a step. A good quality of rubber cement should be applied to the prepared surface. Three coats should be used, each coat being allowed to dry before the next one is applied. The ends of the belt may then be firmly pressed together. The joint thus formed is reinforced either by means of sewing it with a light leather lacing or by inserting small copper rivets. When rivets are used, they should be placed about 1½ inches apart and the rows should be staggered.

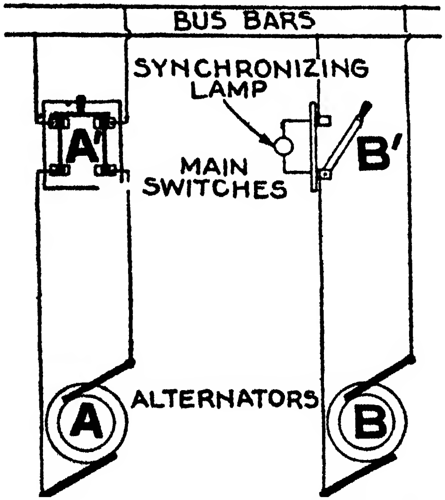
NOTE.—*Parallel operation of alternators.*—To operate alternators in parallel, the machines must have: 1, the same rated voltage; 2, same frequency and 3, similar characteristics. It is not necessary that the machines have the same output capacity. It is, however, of prime importance that the driving engine governors have the same characteristics. Even though the alternators be identical, division of the load between them will depend entirely upon the steam supply to each. The machine getting most steam will deliver the most load, the load of each will be proportional to the steam supplied to it.

NOTE.—*Parallel operation of alternators.*—The machines must be connected to give the same phase rotation. At the instant of cutting in, the phases of both machines must be the same, that is, in unison.

parallel with it. To properly switch in a new machine in parallel with one already in operation and carrying load, requires a complete knowledge of the situation on the part of the attendant, and also some experience.

There are several methods of synchronizing or bringing the alternators in phase, as by the

1. One dark lamp method;
2. Two dark lamp method.



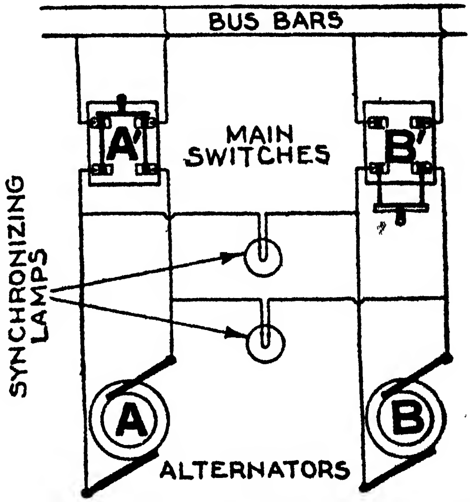


FIG. 4,835.—Synchronizing; *one dark lamp method*. Assuming A, to be in operation, B, may be brought up to approximately the proper speed, and voltage. Then if B, be run a little slower or faster than A, the synchronizing lamp will glow for one moment and be dark the next. When the lamp remains dark the machines are in synchronism and switch may be thrown in.

FIG. 4,836.—Synchronizing, two dark lamp method. When the machines are in phase there will be no difference of pressure between the left hand terminals or between the right hand terminals of the two machines. Hence, if the synchronizing lamps be connected as shown, both will be dark, and the switch may be thrown in connecting the machines in parallel.

3. Brilliant lamp method, or
4. By use of synchronism indicator.

These methods are given in the accompanying illustrations.

The connections for operating alternators in parallel are shown in fig. 4,835. In the illustration the alternator A, is in operation and is supplying current to the bus bars. The alternator B, is at rest. The main pole switch B′, by means of which this machine can be connected into circuit is open.

Now, if the load increase to such extent as to require the service of the second alternator B, it must be switched in parallel with A. In order that both machines may operate properly in parallel, three conditions must be satisfied before they are connected together, or else the one alternator will be short circuited through the other, and serious results will undoubtedly follow.

Accordingly before closing main switch B, it is necessary that

1. The frequencies of both machines be the same;

2. The machines must be in synchronism;

3. The voltages must be the same.

The frequencies are made the same by speeding up the alternator to be cut in, or changing the speed of both until frequency of both machines is the same.

In synchronizing by the one dark lamp method, it is advisable to close the switch when the machines are approaching synchronism rather than when they are receding from it, that is to say; the instant the lamp becomes dark.

An objection to the one dark lamp method is that the filament of the lamp may break, and cause darkness, or the lamp may be dark with considerable voltage as it takes over 20 volts to cause a 100 volt lamp to glow.

NOTE.—*To start two alternators simultaneously.*—After bringing each of them up to its proper speed so as to obtain equal frequencies, the main switches may be closed, thereby joining their armature circuits in parallel. As yet, however, their respective field windings have not been supplied with current, so that no harm can result in doing this. The exciters of these machines after being joined in parallel, should then be made to send *d.c.* simultaneously through the field windings of the alternators, and from this stage on the directions previously given may be followed in detail.

NOTE.—*Alternators driven by gas engines* should have amortisseur windings to counteract the tendency to *hunting* when run in parallel. This counteraction is due to the fact that any sudden change in the speed of the field, generates a current in the amortisseur winding which resists the change of velocity that caused the current.

The voltage of an incoming machine may be adjusted so that it will be the same as the one already in operation, by varying the field excitation with a rheostat in the alternator field circuit.

In synchronizing three phase alternators, three lamps are necessary only to insure that the connections are properly made, after which one lamp is all that is required.

If in synchronizing as in fig. 4,838 the three lamps become bright or dark *simultaneously*, the connections are correct; if, this action take place *successively*, the connections are wrong.

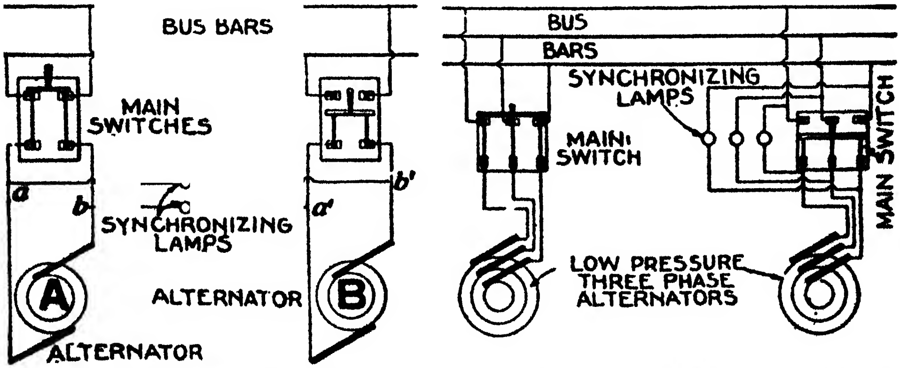


FIG. 4,837.—Synchronizing, brilliant lamp method. When the voltages are equal and the machines in phase, the difference of pressure between *a*, and a given point is the same as that between *a'*, and the same point; this obtains for *b* and *b'*. Accordingly, a lamp connected across *a b'*, will burn with the same brilliancy as across *a' b*; the same holds for the other lamp. When the voltages are the same and the phase difference is 180° the lamps are dark, and as the phase difference is decreased, the lamps glow with increasing brightness until at synchronism they glow with maximum brilliancy. Hence the incoming alternator should be thrown in at the instant of maximum brilliancy.

FIG. 4,838.—Synchronizing three phase alternators, being an extension of the single phase method. Three lamps only are necessary to insure that the connections are properly made after which one lamp is all that is required.

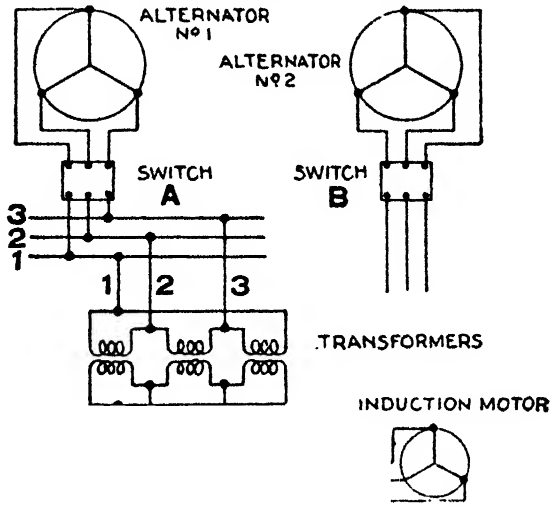
If wrong, transpose the leads of one machine until simultaneous action of the lamps is secured.

In the operation of a synchronizer a hand moves around a dial so that the angle between the hand and the vertical is always

NOTE.—*A disadvantage of the lamp method* is lack of sensitiveness. In place of lamps, some form of synchroscope or synchronizing indicator may be used. These instruments have been described in the chapter on Miscellaneous Meters.

the phase angle between the two sources of electric pressure to which the synchronizer is connected.

If the incoming alternator be running too slow, the hand deflects in



Figs. 4,839 and 4,840.—Test for phase rotation where the original phase markings have been removed. Three small distribution transformers, the primary voltage of which is the same as the voltage of the alternator, are connected to the bus of machine No. 1, and a small three phase motor connected to the secondary of the transformer bank. The connections on the primary side of the transformers may be marked 1,2,3, and the buses to which these leads are connected on machine No. 1 must also be marked 1,2,3. When the switch "A" is closed the induction motor will rotate in a given direction: this must be marked on the motor. The switch "A" is then opened and the transformer primary leads are connected to the buses of machine No. 2. The switch "B" is closed and the motor rotation is noted. If the motor rotate in the same direction as on machine No. 1, then the buses of machine No. 2, are marked 1,2,3, to correspond with the connection of the primary leads of transformer bank. When the rotation of the motor is opposite to that of the test on machine No. 1, then the connection of the transformer bank leads No. 2 and 3, to the buses of machine No. 2, are interchanged and then the buses of machine No. 2, are marked 1,2,3 to correspond with the connections of the transformer bank. The buses 1,2,3 may be termed X,Y,Z or anything else; the main point is that the phase rotation is now definitely found and the machines may be arranged to be connected together accordingly. In making the foregoing tests it is essential that the connections between transformers and transformers and motor be left undisturbed. In order that these machines be placed in parallel the voltage and frequency of the two must be brought to the same point. This necessitates a volt meter and frequency meter on each machine. With voltage and frequency correct the final essential is that the machines be in phase, or, as it is usually termed, in synchronism. For though the voltage and frequency of the machines be exactly the same if they be out of phase 180° and the machines are thrown together it will be equivalent to a short circuit on the machines at twice normal voltage, since machine No. 1 will be maximum positive and machine No. 2 will be maximum negative at the same instant. When the machines are thrown together in exact synchronism and at exact voltage no current can flow between the machines. It will therefore be noted that it is desirable to synchronize properly.

one direction, if too fast, in the other direction. When the hand shows no deflection, that is, when it stands vertical, the machines are in phase. A complete revolution of the hand indicates a gain or loss of one cycle in the frequency of the incoming machine, as referred to the bus bars.

Cutting out Alternator.—When it is desired to cut out of circuit an alternator running in parallel with others, the method of procedure is as follows:

1. Reduce driving power until the load has been transferred

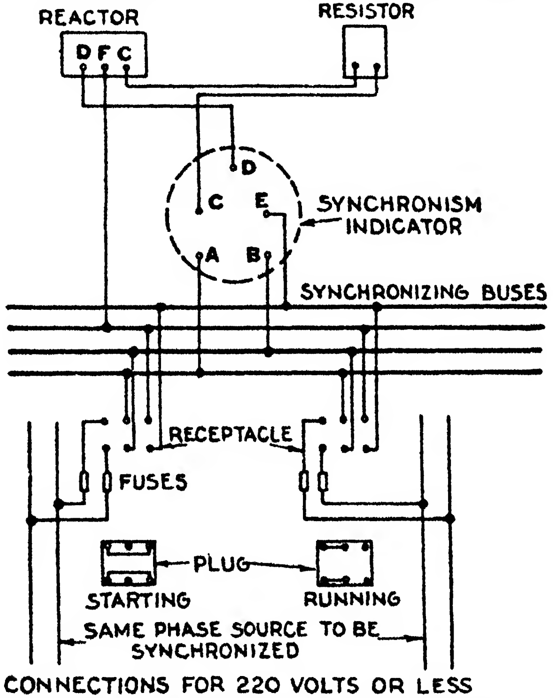


FIG. 4,841.—Connection diagram for synchronizing with synchroscope. The synchroscope shows the exact phase difference at any instant, and also shows whether the incoming machine is running too fast or too slow. At exact synchronism the pointer remains stationary in a vertical position. When the voltage and frequency of the incoming machine are the same as the operating machine and synchronism is indicated, by the synchroscope, the incoming machine is then thrown in parallel with the operating machine by closing the main switch of the incoming machine. It may be found necessary to adjust the load on the two machines. This can only be done by adjusting the governors of the engines driving the alternators. Adjusting the field rheostats after the machines are in parallel only affects power factor and voltage and has no effect on load division. In order to facilitate the adjustment of the engine governors, it is quite usual to arrange a small motor geared to the governor and this motor is then operated from the main switchboard.

to the other alternators, adjusting field rheostat to obtain minimum current;

2. Open main switch;
3. Open field switch.

Never open field switch before main switch.

The ordinary method of cutting out an alternator is to open the main switch without any preliminaries, but an objection to this procedure is that it suddenly throws all the load on the other alternators, and causes "hunting."

Transformers.—The kind of efficiency of transformers the station master is interested in is the *all day efficiency*.*

The usual all day efficiency is about 85 per cent for those of 1 kilowatt capacity, 92 per cent for those of 5 kilowatts capacity, 94 per cent for those of 10 kilowatts capacity, and about 94.5 per cent for those of 15 kilowatts capacity.

Mineral oil is used in oil cooled transformers. *It must be free from moisture.* To test, thrust a red hot iron rod in the oil; if it "crackle," moisture is present. The presence of moisture reduces the insulation value of the oil.

Transformer Definitions

Continuous duty.—A requirement of service which demands operation at substantially constant load for an unlimited period.

Efficiency.—The ratio of the useful power output to the total power input.

Impedance drop.—Vector sum of the resistance drop and the reactance drop.

Indoor transformer.—One which, because of its construction, must be protected from the weather.

*NOTE.—*All day efficiency.*—This expression, as commonly met with in practice, *denotes the percentage that the amount of energy actually used by the consumer is of the total energy supplied to his transformer during 24 hours.*

Intermittent duty.—A requirement of operation or service consisting of alternate periods of load and rest so apportioned and regulated that the temperature rise at no time exceeds that specified for the particular class of apparatus under consideration.

Load losses.—These include I^2R losses in the windings due to load current, stray losses due to stray fluxes in the windings, core clamps, etc., and in some cases with parallel windings, losses due to circulating current.

No-load losses.—These include core losses I^2R losses in the winding due to exciting current and dielectric losses in the insulation.

Outdoor transformer.—One which is so constructed or protected that exposure to the weather will not interfere with its successful operation.

Rating.—The rated *kva.* is the output which can be delivered continuously at rated secondary voltage and rated frequency without exceeding safe temperature limits.

Reactance drop.—Voltage drop in quadrature with the current.

Resistance drop. —Voltage drop in phase with the current.

Subtractive and additive polarity.—Imagine a single phase transformer having two high voltage and two low voltage external terminals. Connect one high voltage terminal to the adjacent low voltage terminal and apply voltage across the two high voltage terminals. Then, if the voltage across the unconnected high voltage and low voltage terminals be less than the voltage applied across the high voltage terminals, the polarity is subtractive; while if it be greater than the voltage applied across the high voltage terminals, the polarity is additive.

Subway transformer.—One which is so constructed that it will operate successfully when submerged in water under specified conditions of pressure and time.

Voltage taps.—A full capacity tap is a tap from a transformer winding on which the unit may be operated at rated *kva.* capacity without exceeding the specified temperature rise. A reduced capacity tap is a tap on which the unit may not be operated at full capacity without exceeding the specified temperature rise.

In the selection of a transformer, one should be chosen, whose parts are so proportioned that the point of maximum efficiency occurs at that load which the transformer usually carries in service.

In many *a.c.* installations, comparatively light loads are carried the greater part of the time, the rated full load or an overload being of short duration. For such purposes special attention should be given to the designing or selecting of transformers having low core losses rather than low resistance losses, because the latter are then of relatively small importance.

The regulation of a transformer may be improved by decreasing the resistances of the windings by employing conductors of greater cross section, or decreasing their reactance by dividing the coils into sections and closely interspersing those of the primary between those of the secondary.

In transformers where there is a great difference in voltage between the primary and secondary windings, however, this remedy has its limitations on account of the great amount of insulation which must necessarily be used between the windings, and which therefore causes the distances between them to become such as to cause considerable leakage of the lines of force.

For the satisfactory operation of transformers in parallel, they must be designed for the same pressures and capacities, their percentages of regulation should be the same and they must have the same polarity at a given instant.

One may satisfy himself as to the first of these conditions by examining the name plates fastened to the transformers, whereon are stamped the values of the respective pressures and capacities of each.

Although equal values of regulation is given as one of the conditions to be satisfied, transformers may be operated in parallel when their percentages of regulation are not the same. Ideal operation, however, can be attained only under the former state of affairs.

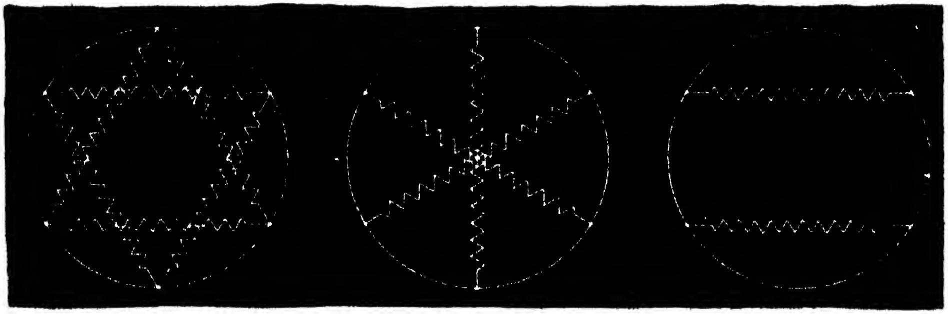
To test a transformer for polarity, join together by means of a fuse wire, a terminal of the secondary winding of each transformer, and then with the primary windings supplied with

NOTE.—*The effect of moisture* is to reduce the insulation value of transformer oil. .06 per cent. of moisture has been found to reduce the dielectric strength of oil about 50 per cent. "Dry" oil will withstand a pressure of 25,000 volts between two 9½ inch knobs separated .15 inch.

NOTE.—*Regulation.*—By definition, regulation of a machine or apparatus in regard to some characteristic quantity (such as terminal voltage, current or speed) is *the ratio of the deviation of that quantity from its normal value at rated load to the normal rated load value.*

normal voltage, connect temporarily the remaining terminals of the secondary windings. The melting of the fuse wire thus connected indicates that the secondary terminals joined together are of opposite polarities, and that the connections must therefore be reversed, whereas if the fuse wire do not melt, it shows that the proper terminals have been joined and that the connections may be made permanent.

The object of this test is, obviously, not to determine the exact polarity of each secondary terminal, but merely to indicate which of them are of the same polarity.



FIGS. 4,842 to 4,844.—Converter connections. Fig. 4,842, double delta connection; 4,843, diametrical connection; 4,844, two circuit single phase connection.

Rotary Converters.—A rotary converter is a reversible machine; that is, if it be supplied with *d.c.* of the proper voltage at its commutator end, it will run as a *d.c.* motor and deliver *a.c.* to the collector rings. While this feature is sometimes taken advantage of in starting the converter from rest, the machine is not often used permanently in this way, its commercial application being usually the conversion of *a.c.* into *d.c.*

When driven by *d.c.* a rotary converter operates the same as a *d.c.* motor, its speed of rotation depending upon the relation existing between the strength of the field and the direct current voltage applied.

If the field be weak with respect to the armature magnetism resulting from the applied voltage, the armature will rotate at a high speed, increasing until the inductors on the armature cut the lines of force in the field so as to develop a voltage which will be equal to that applied.

Again, if the field be strong with respect to the armature magnetism, resulting from the applied voltage, the armature will rotate at a low speed. If, therefore, it be desired to operate the converter in this manner and maintain an alternating current of constant frequency, the speed of rotation must be kept constant by supplying a constant voltage not only to the brushes pressing on the commutator, but also to the terminals of the field winding.

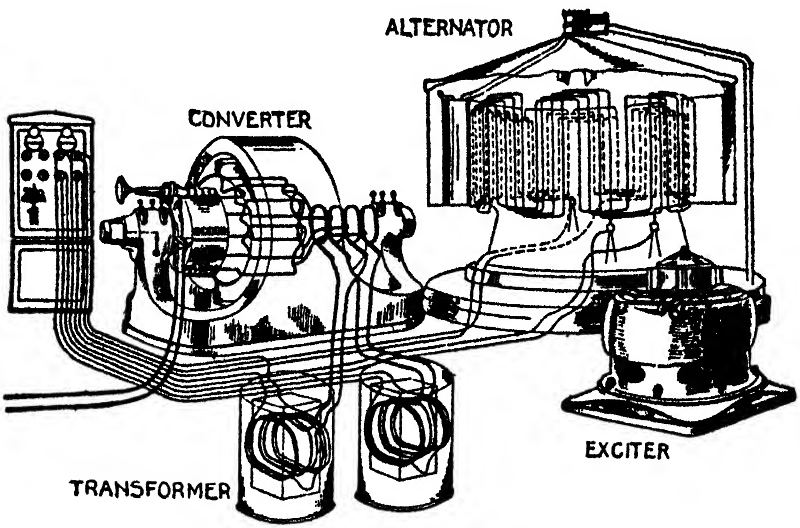
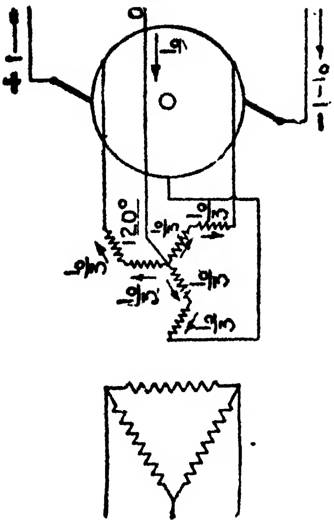


FIG. 4,845.—Wiring diagram of alternator, exciter, transformer and converter showing also switch board connections.

When driven by *a.c.* a rotary converter operates the same as a synchronous motor. The most troublesome part of a converter is its commutator because of the many pieces of which it is composed and the necessary lines along which it is constructed, its peripheral speed must be kept within reasonable limits.

When a rotary converter is operated in the usual manner on an *a.c. circuit, the d.c. may be varied (from zero to a maximum) by changing the value of the alternating pressure supplied to*



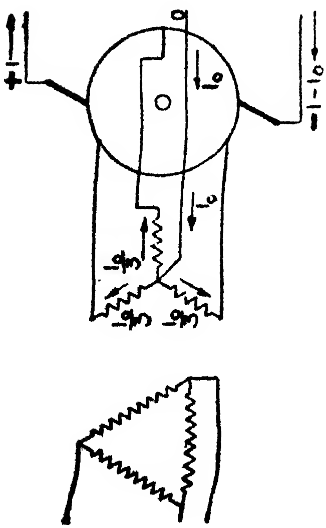


Fig. 4,846.—Wiring diagram for three wire synchronous converter with delta-Y connected step down transformer with the neutral brought out.

Fig. 4,847.—Wiring diagram of three wire synchronous converter with distributed Y secondary. This system avoids the flux distortion due to the unbalanced *d.c.* in the neutral.

the machine, or it may be altered within a limited range by moving the brushes around the commutator, or in a compound wound converter by changing the amount of compounding.

Under ordinary conditions, varying the voltage developed by changing the voltage at the motor end is not practical, hence the voltage developed can be varied only over a limited range. In addition to this, the voltage developed at the direct current end bears always a certain constant proportion to the alternating current voltage applied at the motor end; this is due to the same winding being used both for motor and generator purposes.

In all cases the proportion is such that the alternating current voltage is the lower, being in the single phase and in the two phase converters about .707 of the direct current voltage, and in the three phase converter about .612 of the direct current voltage. It is thus seen that whatever value of direct current voltage be *desired, the value of the applied* alternating current votage must be *lower, requiring in consequence the*

installation of step down transformers at the sub-station for reducing the line wire voltage to conform to the direct current pressure required.

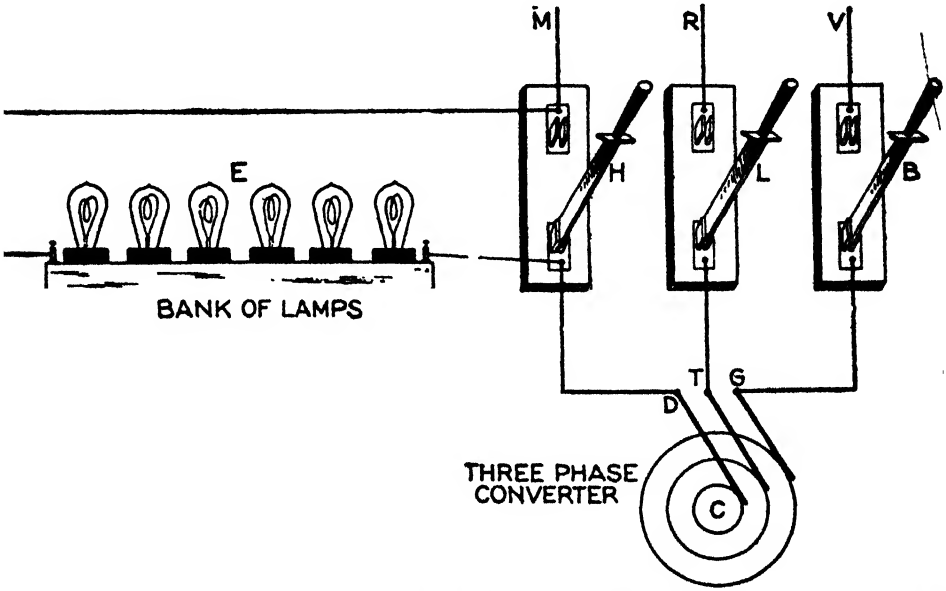


FIG. 4,848.—Wiring diagram showing arrangement of incandescent lamps for determining the proper phase relations in starting a rotary converter. The alternating current side of a three phase converter is shown at C. The three brushes, D, T and G pressing on its collector rings are joined in order to the three single pole switches H, L and B, which can be made to connect with the respective wires M, R, and V, of the alternating current supply circuit. Across one of the outside switches H, for example, a number of incandescent lamps are joined in series as indicated at E, while the three pole switch (not shown) in the main circuit, between the alternator and the single pole switches is open. If then the main switch just mentioned and the middle switch L, be both closed, and the armature of the alternator be brought up to normal speed by running it as a direct current motor, the lamps at E, will light up and darken in rapid succession; the lighting and darkening of the lamps will continue until, by a proper adjustment of the speed, the correct phase relations are established between the alternating current in the supply circuit and the alternating current developed in the armature of the converter. As this condition is approached, the intervals between the successive lighting up and darkening of the lamps will increase until they remain perfectly dark. There is then no difference of pressure between the supply circuit M,R,V, and the rotary converter armature circuit, so the source of the direct current may at that instant be disconnected from the machine, and the switches H and B, closed. If the change over has been accomplished before the phase relations of the two circuits differed, the converter will at once conform itself to the supply circuit and run thereon as a synchronous motor without further trouble.

Starting of Rotary Converters.—There are several methods any one of which may be employed, the choice in any given case depending upon which of them may best be followed under the existing conditions.

Starting with d.c. The same connections would be made between the source of the direct current and the armature terminals on the commutator side of the converter as would be the case were a direct current shunt motor of considerable size to be started; this means that a starting rheostat and a circuit breaker will be introduced into the armature circuit.

An adjustable rheostat will, of course, be connected in the field circuit for regulation. Before starting the converter, however, it is necessary to do certain wiring between the terminals on the collector side of the machine and the alternating current supply wires, in order that the change over from direct current motive power to alternating current motive power may be made when the proper phase relations are established between the alternating current in the supply wires and the alternating current in the armature winding of the converter.

In order that proper phase relations exist, the armature of the converter must rotate at such a speed that each coil thereon passes its proper reversal point at the same time as the alternating current reverses in the supply wires. This speed may be calculated by doubling the frequency of the supply current and then dividing by the number of pole pieces on the converter, but a far more accurate method of judging when the converter is in step or in synchronism with the supply current consists in employing incandescent lamps as shown in fig. 4,848.

Starting with a.c. This may be done by applying the alternating pressure directly to the collector rings while the armature is at rest. There need be no field excitation; in fact the field windings on the separate pole pieces should be disconnected from each other before the alternating voltage is applied to the armature, else a high voltage will be induced in the field windings which may prove injurious to their insulation.

In starting with *a.c.* about 100 per cent more than that required for full load, is necessary.

Wiring of Rotary Converters in Sub-Stations.—Beginning at the entrance of the high pressure cables, first there is the wiring for the lightning arresters, then for the connection in circuit of

the high tension switching devices, from which the conductors are led to bus bars, and thence to the step down transfor

On a three phase system the transformers should be joined in delta connection, as a considerable advantage is thereby gained over the star connection, in that should one of the transformers become defective, the remaining two will carry the load without change except more or less additional heating. Between the transformers and rotary converter the circuits should be as short and simple as possible, switches, fuses, and other instruments being entirely excluded. The direct current from the converter is led to the direct current switchboard, and from there distributed to the feeder circuits.

In large sub-stations containing several rotary converters they are frequently installed to receive their respective currents from the same set of bus bars; that is, they may be operated as alternating current motors in parallel. They are also frequently operated independently from single bus bars, but very seldom in series with each other.

To provide against interruption of service in sub-stations there should be one reserve rotary converter to every three or four converters actually required.

Hunting of Rotary Converters.—In operation the inertia of a converter armature tends to maintain a constant speed; variations in the frequency of the supply circuit will cause a displacement of phase between the current in the armature and that in the line wires, which displacement, however, the synchronizing current strives to decrease.

The synchronizing current, although beneficial in remedying the trouble after it occurs, exerts but little effort to prevent it, and many attempts have been made to devise a plan to eliminate this trouble.

There are several methods used to prevent hunting, namely

1, The employment of a strongly magnetized field relative to that developed by the armature:

2, A heavy fly-wheel effect in the converter;

3, The increasing of the inductance of the armature by sinking the windings thereon in deep slots in the core, the slots being provided with extended heads;

4, The employment of damping devices or amortisseur winding on the pole pieces of the converter.

The damping method is the best method.

The devices employed for the purpose are usually copper shields placed between or around the pole pieces, although in some converters the copper is embedded in the poles, and in others it is made simply to surround a portion of the pole tips.

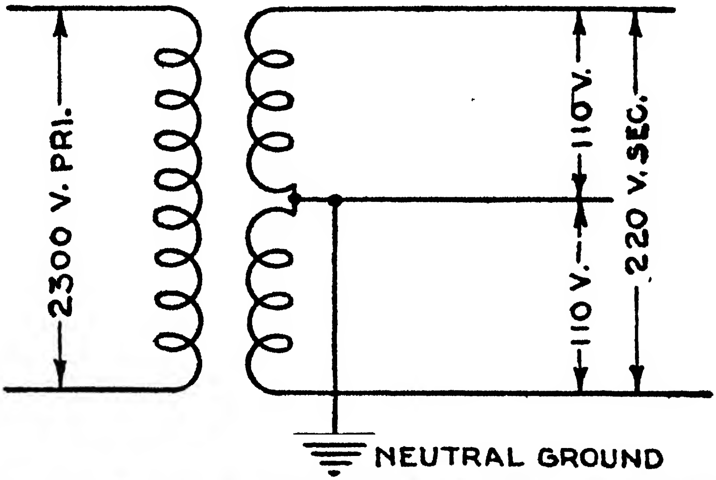


FIG. 4,849.—Low tension neutral grounding for single phase transformers (best method). Here the ground connection is made to the mid-point of the two transformer secondary coils, supplying a 3 wire Edison system. This 3 wire system is now used almost universally, due to the great saving of copper in the lines. This method is desirable where the voltage between the outer wires does not exceed 520 volts.

Grounding Frames and Cases.—All transformer, regulator, generator, motor, starter and similar equipment frames or cases must be solidly grounded. The reason will be apparent from the following explanation.

Consider a pole type transformer that is mounted so as to be within reach when standing on the ground. One of the primary leads of this transformer is considered in contact with the metal case. Therefore, the case will be charged with full line voltage. It is readily apparent that

anyone touching this case while standing on the ground would receive a shock of line voltage to ground just as if contact were made with a bare line. This would be true of any other piece of electrical equipment. Therefore, for safety all equipment frames and cases should be grounded.

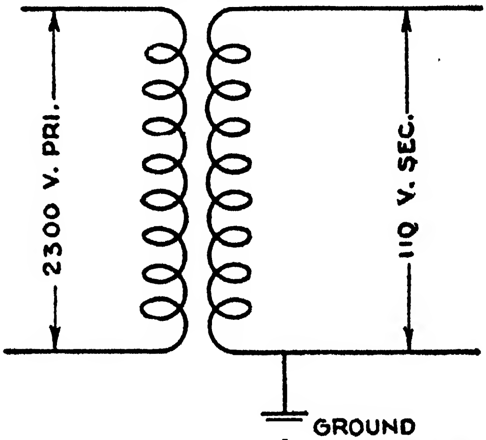
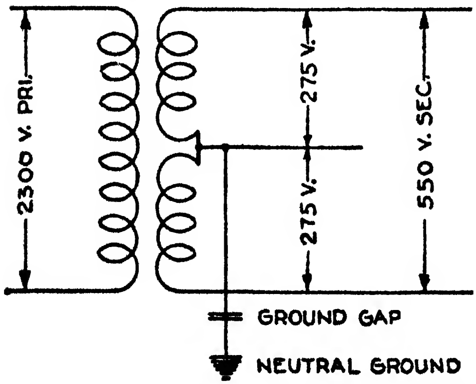
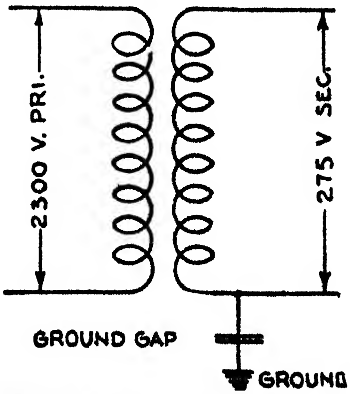


Fig. 4,850.—Low tension grounding for single phase transformer, two wire system. This method should not be used for pressures over 260 volts. The ground wire should be of the same size as the transformer leads.





Figs. 4,851 and 4,852.—Low tension grounding for transformers having a primary pressure of 1,000 volts or more. A breakdown of the insulation between the primary and secondary coils will throw the primary voltage on the secondary circuit and a charging current shock from such a voltage will be dangerous. Therefore, a path to ground must be provided as here shown. The ground gap which is introduced into the ground circuit insulates the neutral from ground when the system operates at normal pressure, thus a contact from line to ground will only give a charging current shock. However, where the coil insulation breaks down between primary and secondary of the transformer and the primary voltage leaks into the secondary system, then the ground gap breaks down and passes the primary voltage to ground safety.

N.E.M.A. Transformer Instructions

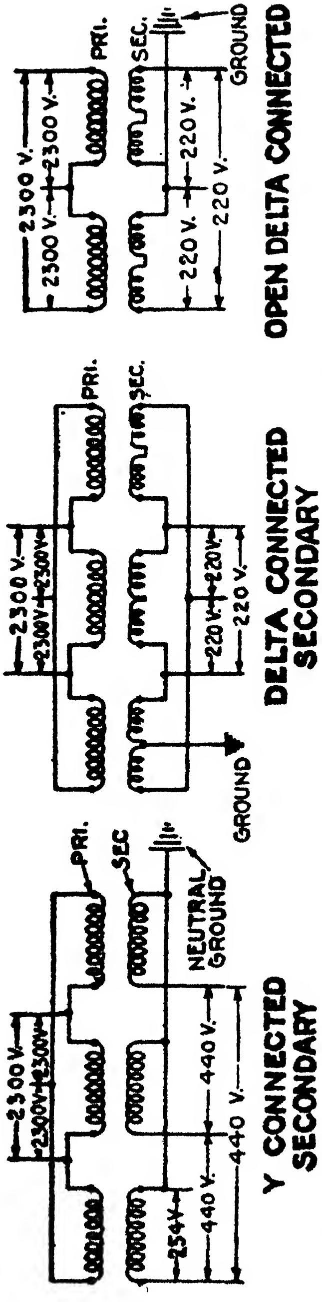
Location.—Accessibility, ventilation and ease of inspection should be given careful consideration in locating transformers.

Handling.—When lifting a transformer the lifting cables nust be held apart by a spreader to avoid bending the lifting studs or other parts of the structure. When working about a transformer particular care must be taken in handling all tools and other loose articles, since any thing metallic dropped among the windings and allowed to remain there may cause a breakdown.

Inspection.—When received, examination should be made before removing from cars and if any injury be evident or any indication of rough handling be visible, railroad claim should be filed at once and the manufacturer notified. Before being set up, a transformer should be inspected for breakage, injury or misplacement of parts during shipment and thoroughly examined for moisture. In addition all accessible nuts, bolts and studs should be tightened. If transformers be water cooled, the cooling coils should be tested for leaks at a pressure of 80 to 100 lbs. per sq. in. When pressure is obtained, the supply should be disconnected and after one hour it should be determined whether any fall in pressure be due to a leak in the coil, or is in the fittings at the ends of the coil.

Where transformers are shipped filled with oil, samples of oil should be taken from the bottom and tested.

Drying Core and Coils.—There are a number of approved methods of drying out transformer core and coils, any one of which will be satisfactory if carefully performed. However, too much stress cannot be laid upon the fact that if carelessly or improperly performed, great damage may result to the transformer insulation through over heating. The methods in use may be broadly divided into two classes: 1, drying with the core and coils in the tank with oil; 2, drying with the oil removed. The core and coils may or may not be removed from the tank. Under the first class, the moisture is driven off by sending current through the winding while immersed in oil, with the top of the tank open to the air, or some other arrangement made for adequate ventilation. This may be done by 1, the short circuit method (to be used if the transformer be new or has been out of service without oil any length of time); 2, the normal operation method to be used if the transformer be already in service but show moisture condensation and the transformer cannot be shut down to apply the short circuit method.



FIGS. 4,853 to 4,855.—Low tension neutral point grounding of 3 phase systems illustrating the grounding Y, Δ and V connected transformer banks: With delta and open delta connected transformer banks the maximum voltage between lines that may be direct grounded is 260 volts. The Y connected transformer bank may be direct grounded on pressures up to 440 volts between lines. On 550 volts, 3 phase Y connected banks, the neutral should be grounded through a gap.

Putting New Transformer in Service.—When the voltage is first applied to transformer it should, if sible, be brought up slowl to its full value so that an wrong connection or o trouble may be discovered before damage results. After full voltage has been applied successfully, the transformer should preferably be operated in that way for a short period without load. It should be kept under observation during this time and also during the first few hours that it delivers load. After 4 or 5 days' service it is advisable to test the oil again for moisture.

Filling Transformers.—Metal hose must be used instead of rubber hose, because oil dissolves the sulphur contained in rubber and may cause trouble by the sulphur attacking the copper. Pole mounted transformers may be filled with oil, either before or after mounting, as desired. It is sometimes necessary to add oil a short time after the transformer has been installed, due to the fact that the installation will absorb a certain amount of oil. When the transformer oil is replenished care should be taken that no moisture finds its way inside the case.

N.E.M.A. Motor Instructions

Unpacking and Handling.—When unpacking and handling machines the windings and other parts should be protected from damage. To prevent sweating, the windings of a machine that have been exposed to low temperature, should not be uncovered until they have had sufficient time to attain a temperature nearly as high as that of the room in which they are to be unpacked. Whenever practical, a complete machine should be moved as a unit. This eliminates many possible troubles with windings, armature, slip rings, etc. When necessary to move the armature or rotor alone, the only safe method of supporting it while either moving or stationary, is by slings or blocking under the shaft or by a padded cradle under the core laminations. The whole armature surface may be considered as subject to damage either to the bands, wedges, clips or insulation unless properly handled. Every precaution should be taken to avoid damaging any of the windings or other parts.

Drying Out.—Small machines can be baked in ovens and larger units can be dried by passing current through the windings. In either case, however, the temperature should be kept within a maximum of 185° F.

Erection.—Machines must be lined up on their foundations, so that the

NOTE.—***High tension neutral grounding.***—This method of grounding was devised mainly for the protection of the electrical system. The benefits of grounding the high tension neutral of the three phase system is two fold. 1, it reduces the voltage stresses on all apparatus insulation to ground; 2, it converts any accidental ground fault on any line into a short circuit on the corresponding phase, tripping the faulty circuit clear of the alternator, providing of course, that the circuit is equipped with proper protective apparatus in the way of circuit breakers or fuses where the latter are adequate for this purpose. The clearing of a circuit on which there exists a ground is very desirable as it safeguards against trouble of much greater magnitude. On a system where the voltage is relatively low, there may be no great advantage in the further reduction of voltage to ground.

NOTE.—***Low tension neutral grounding.*** The method is here considered as applying to all systems of 550 volts or less and fed from the secondary of ordinary distribution transformers. The purpose of this system of grounding is to insure against higher than normal voltage being present on the low tension system, and therefore, the possible danger to human life is minimized. The grounding of the low tension neutral also eliminates an arcing ground, thereby reducing fire risk in buildings, etc. Lastly, it ensures the disconnection of the faulty part of the low tension system through the operation of fuses or circuit breakers. Where the high tension primary of the transformer is connected to a high tension grounded neutral system and a break down of insulation occurs between primary and secondary coils, the grounding of the low tension neutral usually provides a short circuit path for the high tension currents and this at once disconnects the faulty transformer from the high tension line by the operation of the fuses. This, however, does not occur when the primary of the transformer is connected to a high tension ungrounded neutral system. This adds another point in favor of high tension neutral grounding for the breakdown of insulation between primary and secondary coils of distribution transformers is by no means uncommon, especially in districts subjected to heavy lightning storms.

driving and driven shafts are parallel. Driving and driven pulleys must be in line so that the belt will run true.

Grounding of Frames.—This is recommended for all motors. If the frame be insulated from the ground, the strain on the insulation of the windings will be decreased, but danger to the attendants will be increased. If such insulation be desired, the foundation should be capped by a stout wooden frame bolted to the masonry, care being taken that the bolts are so placed that they do not make electrical contact with the bolts which secure the alternator frame to the wooden cap, or with the frame itself. This wooden cap may be covered with some insulating waterproof paint or compound.

Lubrication.—When a machine is first started, the oil rings should be observed to see that they are turning and the bearing housings watched to see that they are not overheating. Oil wells should be filled with petroleum oil (not vegetable or animal oil) sometimes specified as high grade dynamo, or light engine oil. Experience has shown that animal or vegetable oils or grease, or admixtures of them with mineral or petroleum oil, will dry and gum, and by gumming the ducts and oil rings, prevents the free flow of oil to the bearings. Oil leakage at the drainage plugs can be avoided by dipping the plugs in a mixture of red lead and shellac before inserting. It is advisable to apply a little clean lubricating oil to collector rings regularly. The oil may be applied with a piece of cloth or chamois skin.

N.E.M.A. Control Equipment Instructions

Contacts.—The contacts of an electric controller assume a position of first importance. Of whatever type, they must be kept clean, pressure maintained and replaced when worn.

Contactors.—To keep magnetic contactors in proper working order a regular inspection should be made to maintain a correct relation between the action of the contacts, iron circuit and coil. Assurance that the iron circuit is closed and sealed with a positive action, and that the contacts have sufficient "roll" or pressure will prevent many controller complaints.

Relays.—Follow the manufacturer's instructions furnished with relays.

Low Voltage Devices.—The proper holding and releasing action of low voltage coils, under voltage coils, and mechanisms is dependent on both mechanical adjustment and application of the voltage (and frequency on alternating current systems) specified on the name plate. The spring and gravity return mechanism should be kept in proper adjustment to avoid too violent return. *A.C.* release mechanism should be inspected to see

that the iron circuit is properly sealed and that the pole pieces are cleaned of rust and make a true flat contact. Care on this point will prevent humming and failure of coils from excessive current due to open iron circuits.

Connections and Wiring.—Terminals and connection studs on controllers, accessories and resistors should be gone over regularly and tightened to avoid poor contact and improper functioning of the apparatus.

Lubrication.—Oil on controllers should be applied only to parts needing oil. Any excess oil on surfaces should be wiped off to prevent accumulation of dust and dirt. Oil should be applied carefully and sparingly to such parts of a controller as may be specified by the manufacturer in his instructions.

TEST QUESTIONS

1. *What items are included in the term "management"?*
2. *What should be considered to properly select a machine?*
3. *Describe in detail how various power plant apparatus are properly selected.*
4. *What are the uses of single phase and polyphase motors of various types?*
5. *Describe the use of synchronous motors for the dual purpose of power and power factor correction.*
6. *Give the application of "general purpose" motors.*
7. *Give the effects of variation of voltage and frequency upon the performance of induction motors.*
8. *Explain the markings placed on terminals of electric power apparatus.*
9. *Give some points relating to rotors and phase rotation of rotating apparatus.*
10. *Explain the rating of alternators.*

11. *What may be said with respect to the voltage taps of transformers?*
12. *Give a few points relating to the installation of machines in power houses.*
13. *Give some information on belts and pulleys.*
14. *Explain horse power and torque calculations.*
15. *Describe the operation of an alternator under various conditions.*
16. *What are the various methods of synchronizing alternators so that they will run in parallel?*
17. *Describe the method of cutting out an alternator.*
18. *What kind of transformer efficiency is important to the station manager?*
19. *Is a rotary converter a reversible machine?*
20. *Give the method of starting a rotary converter.*
21. *How are rotary converters wired in sub-stations?*
22. *Describe the hunting of rotary converters.*
23. *Explain how and why frames and cases should be grounded.*

CHAPTER 92

Testing Indicating Instruments

Before making tests on *a.c.* motors, alternators, transformers, or other machines, the instruments used should be tested so that accurate results may be obtained. The explanations then may be regarded as a preliminary to chapters 93 and 94.

Electrical Indicating Instruments.—In the manufacture of most measuring instruments, the graduations of the scale are made at the factory, by comparing the deflections of the pointer with voltages as measured on standard apparatus.

The volt meters in most common use have capacities of 5, 15, 75, 150, 300, 500 and 750 volts each, although in the measurement of very low resistances such as those of armatures, heavy cables, or bus bars, volt meters having capacities as low as .02 volt are employed.

The difference between the design of direct current volt meters of different capacities lies simply in the high resistance joined in series with the fine wire coil. This resistance is usually about 100 ohms per volt capacity of the meter, and is composed of fine silk covered copper wire wound non-inductively on a wooden spool.

In the operation of an instrument, if the pointer when deflected do not readily come to a position of rest owing to friction in the moving parts, it may be aided in this respect by gently tapping the case of the instrument with the hand; this will often enable the obstruction, if not of a serious nature, to be overcome and an accurate reading to be obtained.

In a two scale volt meter, one scale is for low voltage readings and the other for high voltage readings; on these scales the values of the graduations for low voltages are usually marked with red figures, while those for high voltages are marked with black figures.

A volt meter carrying two scales must also contain two resistances in place of one; a terminal from each of these coils must be connected with a separate binding post, but the remaining terminal of each resistance is joined to a wire which connects through the fine wire coil with the third binding post of the meter. The two first mentioned binding posts are usually mounted at the left hand side of the meter and the last mentioned binding post and key at the right hand side.

The resistance corresponding to the high reading scale is composed of copper wire having the same diameter as that constituting the resistance for the low reading scale, but as the capacity of the former scale is generally a whole number of times greater than that of the latter scale, the resistances for the two must bear the same proportion.

In connecting a two scale volt meter in circuit, the single binding post is always employed regardless of which scale is desired.

If, then, the voltage be such that it may be measured on the low reading scale, the other binding post employed is that connected to the lower of the two resistances contained within; if, however, the pressure be higher than those recorded on the low reading scale, the binding post connected to the higher of the two resistances contained within is used.

Inasmuch as the capacities of the scales are usually marked on or near the corresponding binding posts, there will generally be no difficulty in selecting the proper one of the two left hand binding posts.

When the binding posts of a two scale volt meter are not marked and only an approximate idea is possessed of the voltage to be measured, it is always advisable to connect to the binding post corresponding to the high reading scale of the meter.

This is done in order to determine if the measurement may not be made safely and more accurately on the low reading scale. In any case, some knowledge must be had of the voltage at hand, else the high reading portion of the instrument may be endangered.

Too much care cannot be taken to observe these precautions whenever the volt meter is used, for the burning out or charring of the insulation either in the fine wire coil or in the high resistance of the meter by an excessive current, is one of the most serious accidents that can befall the instrument.

If a voit meter has been subjected to a voltage higher than that for which it was designed, yet not sufficiently high to injure the insulation, but high enough to cause the pointer to pass rapidly over the entire scale, damage has been done in another way. The pointer being forced against the side of the case in this manner is more or less bent and so introduces an error in the readings that are afterward taken.

The same damage will be done if the meter be connected in circuit so that the current does not pass through it in the proper direction, although in this case the pointer is not liable to be bent so much as when it is forced to the opposite side of the meter by an abnormal current, since then it has gained considerable momentum which causes a more severe impact.

The extent of the damage may be ascertained by noting how far away from the zero mark the pointer lies when no current is passing through the instrument. If this distance be more than two-tenths of a division, the metal case enclosing the working part should be removed and the pointer straightened by the careful use of a pair of pinchers.

Indicating instruments should not be placed near conductors carrying large currents.

A fall or a rough handling of an instrument at once shows its effect on the readings, for as much harm is done as would result from a similar treatment of a watch.

How to Take Readings.—The deflection of the pointer should be read to tenths of a division; this can be done with considerable accuracy, especially after a little practice.

For very accurate results, a temperature correction should be applied to compensate for the effect which the temperature of the atmosphere has upon the resistance of the meter when measurements are being taken. In ordinary station practice the temperature correction is negligible, being

for resistance corresponding to the high scale in first class meters, less than one-quarter of 1 per cent. for a range of 35 degrees above or 35 degrees below 70 degrees Fahrenheit.

Errors in Station Volt Meters.—Since they are usually connected permanently in circuit; a certain amount of heat is developed in the wiring of the instrument.

The effect of this heat increases the volt meter resistance and consequently reduces the current below that which otherwise would pass through

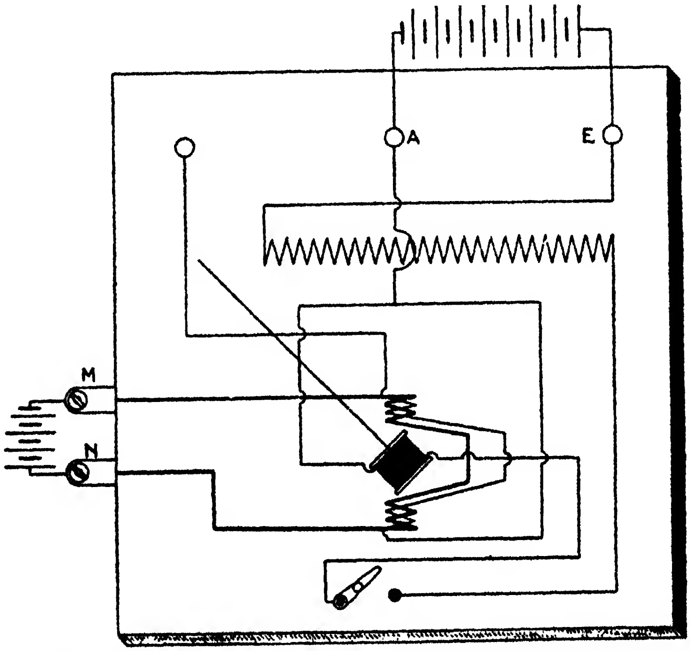


FIG. 4,856.—Diagram of connections for calibrating a watt meter.

the meter; since the deflections of the pointer are governed by the strength of the current, station volt meters invariably indicate a voltage slightly lower than that which actually exists across their leads.

Checking Up a Recording Watt Meter.—This may conveniently be done by noting the deflections at short intervals on

an ammeter connected in circuit, and also the readings on the dial of the recording watt meter during this period. If this test be continued for an appreciable time, the product of the pressure in volts, the current in amperes, and the time in hours, should equal the number of watt hours recorded on the counters of the dial.

Calibrating a Watt Meter.—The calibration of a portable watt meter is accomplished with direct current of constant value which is passed through the series winding by connecting the source thereof with the current terminals as in fig. 4,856.

A direct current voltage which may be varied throughout the range of the watt meter is also applied to the instrument between the middle and right hand pressure terminals A and E, the wiring in the meter between these terminals being such that its differential winding is then cut out of circuit.

The method of procedure consists in comparing the deflections on the watt meter at five or six approximately equidistant points over its scale with the corresponding products of volts and amperes used to obtain them.

The changes in the watt meter deflections are effected by merely varying the voltage, the value of the current being maintained constant at a value which represents the full current capacity of the meter.

How to Get Accurate Ammeter Readings.—For precision measurements an ammeter should be cut out of circuit except while taking a reading, because of the error introduced by the heating effect of the current.

In an ammeter having a capacity of 50 amperes, the error thus introduced will be less than 1 per cent. if connected continuously in circuit with a current not exceeding three-quarters this capacity.

All ammeters of 100 amperes capacity may be used indefinitely in circuit with less than 1 per cent. error up to one-half its capacity, and for five minutes at three-quarters capacity without exceeding the 1 per cent. limit.

Meter Testing with Standard.—In testing a meter, by comparing it with a standard, in order to obtain the best results there should be one man at each meter so that simultaneous readings may be taken on both instruments, and the man at the standard meter should maintain the voltage constant while

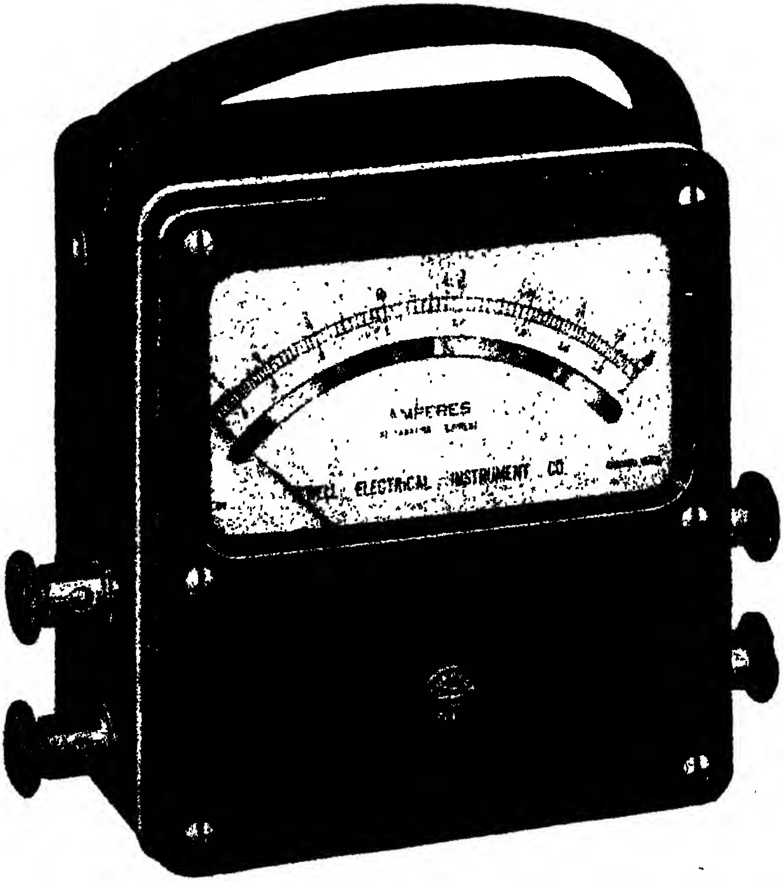


FIG. 4,857.—Jewel two scale *a.c.* portable testing ammeter. The construction uses a special coil which has several windings so arranged that the several scales check in their characteristics and consequently a single set of divisions is supplied with the necessary sets of figures.

a reading is being taken, by means of a rheostat in the field circuit of the generator supplying the current.

Each meter should be checked or calibrated at five or six approximately equidistant points over its scale; the adjustable resistance being varied each time to give a deflection on the standard meter of an even number of divisions and the deflection on the other meter recorded at whatever it may be. Having obtained the necessary readings, the calculation of the constant or multiplying factor of the meter undergoing test is next in order.

This may best be shown by taking an actual case in which a 150 scale volt meter is being tested to determine its accuracy. The data and calculations are as follows:

Readings on standard meter	Readings on meter tested	Constant
150	149.2	150 ÷ 149.2 = 1.005
125	125.0	125 ÷ 125.0 = 1.000
100	98.9	100 ÷ 98.9 = 1.011
75	73.6	75 ÷ 73.6 = 1.019
50	50.0	50 ÷ 50.0 = 1.000
25	24.8	25 ÷ 24.8 = 1.008
		6.043

Average constant for six readings, 6.043 ÷ 6 = 1.007.

It may be stated in general that before taking the readings for this test, the zero position of the pointer on the meter tested should be noted, and if it be more than two-tenths of a division off the zero mark, the case of the meter should be removed and the pointer straightened.

Furthermore, it will be noticed from the readings here recorded that the test is started at the high reading end of the scale; this is done in order that the pointer may gradually be brought up to this spot, by slowly cutting out of circuit the adjustable resistance, and thus show whether or not the pointer has a tendency to stick at any part of the scale. If the meter seem to be defective in this respect, it should be remedied either

NOTE.—***The 150 scale ammeter*** may be left in circuit for an indefinite length of time at one-third its full capacity, and for three minutes at one-half its full capacity, with a negligible error.

NOTE.—When currents larger than 300 amperes have to be measured, ammeter shunts are generally employed, although ammeters up to 500 amperes capacity are manufactured.

NOTE.—***Ammeters of 200 and of 300 ampere capacities*** must not continuously carry more than one-quarter of these loads respectively if the readings are to have an accuracy within 1 per cent. nor more than one-half these respective numbers of amperes for three minutes if the same degree of accuracy be desired.

by bending the pointer or scale, or by renewing one or both of the jewels, before the comparison with the standard is commenced.

It is obvious from the readings recorded from the 150 scale volt meter, that as compared with the corresponding deflections of the standard, the former are a trifle low.

In order to determine for each observation how much too low they are, it is necessary to divide each reading on the standard by the corresponding reading on the meter tested. The result is the amount by which a deflection of this size on the meter tested must be multiplied in order to

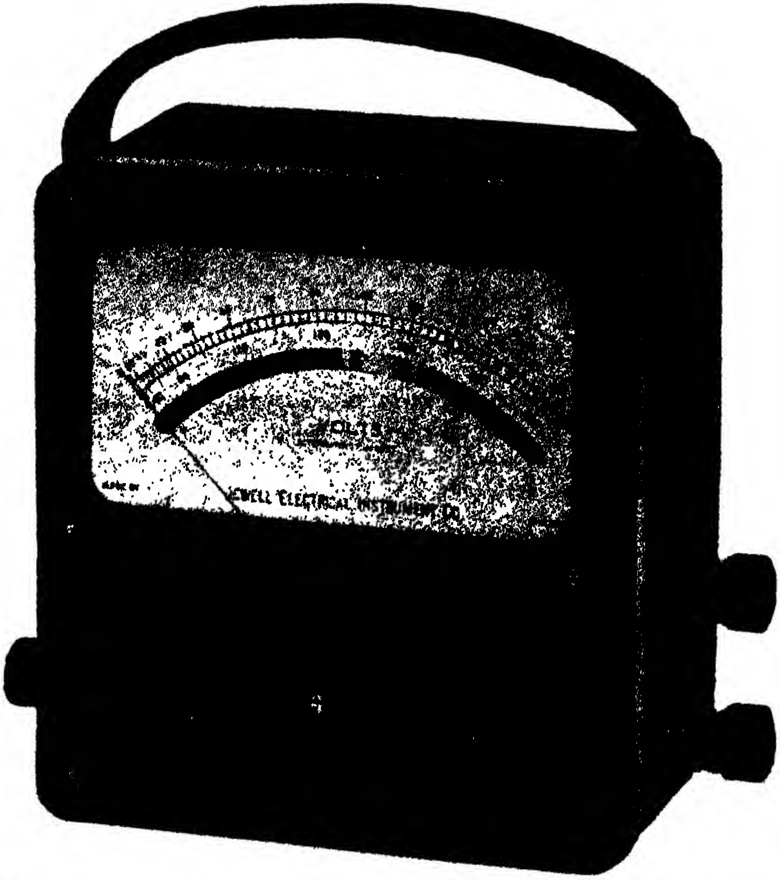


FIG. 4,858.—Jewel two scale *a.c.* portable testing volt meter. The *a.c.* movement used is shielded and is an advanced design of the repulsion iron vane type, embodying a bakelite form for the coil, a moulded bakelite damping chamber and a moving element, which is light, but rugged.

obtain the exact reading. This multiplier is called a constant, and as shown, a constant is determined for each of the six observations.

The average constant for the six readings is then found, and this is taken as the constant for the meter as a whole; that is, whenever this 150 scale volt meter is used, each reading taken thereon must be multiplied by 1.007 in order to correct for its inaccuracy.

The most convenient and systematic way of registering the constant of a meter is to write it, together with the number of the meter and the date of its calibration, in ink on a cardboard tag and loop the same by means of a string to the handle or some other convenient part of the meter.

Calibration of a Two Scale Volt Meter.—The complete calibration of a two scale volt meter does not, as might be supposed, necessitate that the readings on both scales be checked with standards, for since the resistance corresponding to the one scale is always some multiple of the resistance of the other, the constants of the two scales are proportional.

For instance, if S = the reading at the end of the high scale of the volt meter; S^1 = the reading at the end of the low scale of the volt meter; R = the resistance in the meter corresponding to the high scale; R^1 = the resistance in the meter corresponding to the low scale; K = the constant for the high scale, and K^1 = the constant for the low scale. Then

$$SK \div R = S^1K^1 \div R^1$$

from which

$$K^1 = SKR \div S^1R$$

That is to say, if the respective resistances corresponding to the two scales be known, and the constant of the high scale be determined by comparison with a standard, then by aid of these known values and the maximum readings on the two scales, the constant of the low scale may be calculated. It is also possible to calculate the constant of the high scale if the constant of the low scale be known, together with the values of the resistances corresponding to the two scales; for from the equation previously given,

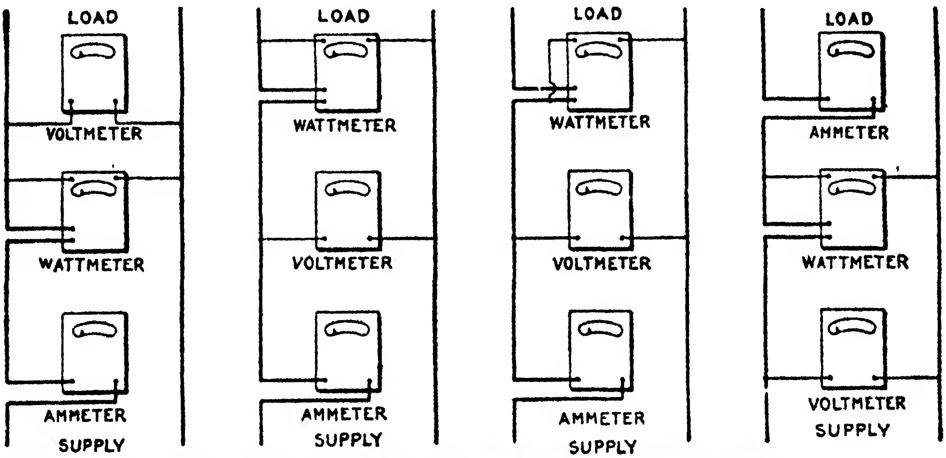
$$K = RS^1K^1 \div R^1S$$

There are a number of tests that are easily made and which require only ordinary ammeters, volt meters and watt meters.

NOTE.—*Tuning up a meter* consists in straightening the pointer; varying the tension of the spiral springs; renewing the jewels in the bearings; altering the value of the high resistance, and, in the case of a direct current instrument, strengthening the permanent magnet.

A knowledge of these tests will be found useful to those having charge of *a.c.* motors. The tests which follow are of simple nature and present no difficulties.

In motor testing, by the methods illustrated in the accompanying cuts, it is assumed that the motor is loaded in the ordinary way by belting or direct connecting the motor to some form of load, and that the object is to determine whether the motor is over or under loaded, and approximately what per cent. of full load it is carrying. All commercial motors have name plates, giving the rating of the motor and the full load current



Figs. 4,859 to 4,862.—How to connect instruments for power measurements.

in amperes. Hence the per cent. of load carried can be determined approximately by measuring the current input and the voltage. If an efficiency test of the apparatus be required, it becomes necessary to use some form of absorption by dynamometer, such as a Prony or other form of brake. The output of the motor can then be determined from the brake readings. The scope of the present treatment is, however, too limited to go into the subject of different methods of measuring the output of the apparatus, and is confined rather to methods of measuring current input, voltage, and watts. The accuracy of all tests is obviously dependent upon the accuracy of the instruments employed.

Before accepting the result obtained by any test, especially under light or no load, correction should be made for wattmeter error. See watt meter error table on page 2,885.

TEST QUESTIONS

1. *What precautions should be taken with testing instruments in making tests?*
2. *How are the scales on electrical instruments made?*
3. *What range of voltage is most common on the scales of volt meters?*
4. *How do* d.c. *and* a.c. *instruments differ?*
5. *How may the pointer of an instrument be quickly brought to rest?*
6. *Explain the reading of two scale instruments.*
7. *What precautions should be taken in connecting up a two scale volt meter?*
8. *Explain the use of each scale in a two scale volt meter.*
9. *Explain how to take readings.*
10. *How may a volt meter be easily damaged?*
11. *What should be done in taking readings to obtain accurate results?*
12. *What errors occur in station volt meters?*
13. *Should temperature correction be made for ordinary station instruments?*
14. *Explain the effect of heat in introducing an error.*
15. *Explain how to check up a watt meter.*
16. *How is a watt meter calibrated?*
17. *How are accurate ammeter readings obtained?*
18. *How should ammeters of various capacities be used?*
19. *How is a meter tested with a standard?*
20. *How close should a meter read for the zero position?*

21. *What is the most convenient way to register the constant of a meter?*

22. *Explain how to calibrate a two scale volt meter.*

23. *What are the usual remedies in tuning up a meter?*

CHAPTER 93

Transformer Testing

In the early days of transformer building, before the commercial watt meter had been perfected, leakage or exciting current was the criterion of good design. After the introduction of the watt meter, core loss became the all important factor, and for a long time the question of leakage current was lost sight of. With the introduction of silicon steel, leakage or exciting current again assumed prominence.

Keeping in mind the fact that all characteristics of a transformer are of more or less importance, it is essential that the user of such apparatus have at hand the necessary facilities for making tests of all such variable quantities. The tests which all users of transformers should make, are given in this chapter.

Transformer Copper Loss by Watt Meter Measurement and Impedance.—At first glance, this method, as shown in fig. 4,863, would seem better than the calculation of loss after measurement of the resistance. However, it should be noted that the watt meter is, in itself, subject to considerable error under the low power factor that will exist in this test.

The secondary of the transformer is short circuited, and a voltage applied to the primary which is just sufficient to cause full load primary current. If full current pass through the primary of the transformer with

the secondary short circuited, the secondary will also carry full load current. With connections as shown in fig. 4,863 and with the full load current, the volt meter indicates the impedance volts of the transformer. This divided by the rated voltage gives what is called the *per cent. impedance of the transformer*. In a commercial transformer of 5 *kw*, this should be approximately 3 per cent.

The iron loss of the transformer under approximately 3 per cent. of the normal voltage will be negligible, and the losses measured will be the sum of the primary and secondary copper losses.

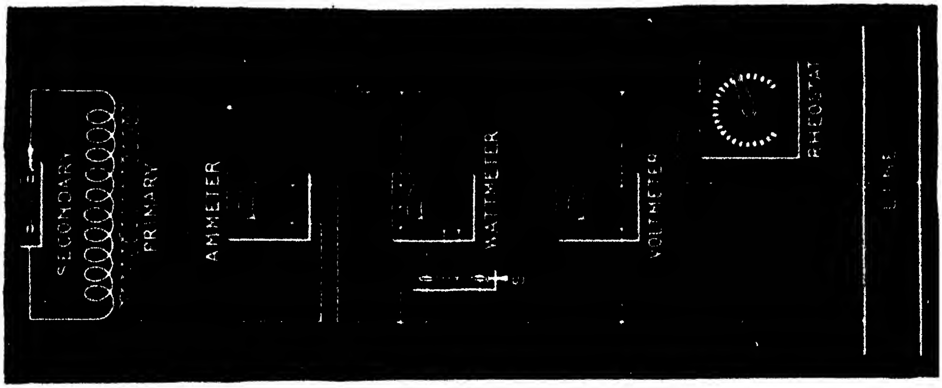


FIG. 4,863.—Transformer copper loss by watt meter measurement and impedance.

As in the discussion of the core loss measurements, the watt meter readings must be corrected for the loss in its pressure coil, the method of correction being the same as that discussed under the core loss measurement. If the impedance volts, as measured, be divided by the primary current, the impedance of the transformer is obtained. The reciprocal of this quantity is known by the term "admittance." *When two or more transformers are connected in parallel they divide the load in proportion to their admittance.* It is, therefore, important that the users of transformers know the impedance of the apparatus

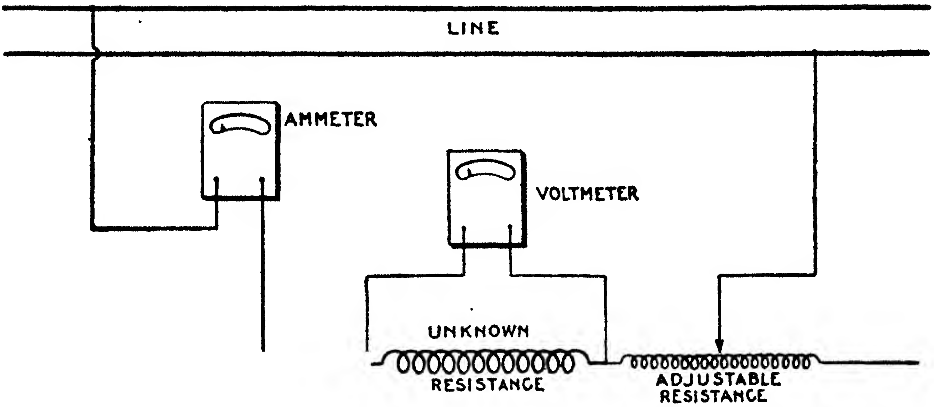


FIG. 4,864.—Resistance measurement by "drop" method. The circuit whose resistance is to be measured, is connected in series with an ammeter and an adjustable resistance to vary the flow of current. A volt meter is connected directly across the terminals of the resistance to be measured, as shown in the figure. According to Ohm's law $I = E \div R$, from which, $R = E \div I$. If then the current flowing in the circuit through the unknown resistance be measured, and also the drop or difference of pressure, the resistance can be calculated by above formula. In order to secure accurate determination of the resistance such value of current must be used as will give large deflections of the needle on the instruments employed. A number of independent readings should be taken with some variation of the current and necessarily a corresponding variation in voltage. The resistance should then be figured from each set of readings and the average of all readings taken for the correct resistance. Great care must be taken, however, in the readings, and the instruments must be fairly accurate. ***For example,*** suppose that the combined instrument error and the error of the reading in the volt meter should be 1 per cent., the reading being high, while the corresponding error of the ammeter is 1 per cent. low. This would cause an error of approximately 2 per cent. in the reading of the resistance. In making careful measurements of the resistance, it is also necessary to determine the temperature of the resistance being measured, as the resistance of copper increases approximately .4 of 1 per cent. for each degree rise in temperature. Use is made of this fact for determining the increase in temperature of a piece of apparatus when operating under load. The resistance of the apparatus at some known temperature is measured, this being called the cold resistance of the apparatus. At the end of the temperature test the hot resistance is taken. Assume the resistance has increased by 15 per cent. This would indicate a rise in temperature of 37½ degrees above the original or cold temperature of the apparatus. Suppose then that in measuring the cold resistance, results are obtained which are 2 per cent. low, and that in measuring the hot resistance, there be 2 per cent. error in the opposite direction. This would mean that a total error of 4 per cent. had been made in the difference between the hot and cold resistances, or an error of 10 degrees. The correct rise in temperature is, therefore, about 27½ instead of 37½ degrees. In other words, an error of 2 per cent. in measuring each resistance has caused an error of approximately 36½ per cent. in the measurement of the rise in temperature. The constant .4 which has been used above is only approximate and should not be used for exact work. For detail instructions of making calculations of resistance and temperature, see "Standardization Rules of the A.I.E.E."

used, in order to determine whether two or more transformers will operate satisfactorily in parallel.

For accurate measurement of impedance the volt meter should be connected directly across the terminals of the transformer rather than as shown in fig. 4,863.

The usual and best method of obtaining copper losses is to separately measure the primary and secondary resistance and calculate from these the primary and secondary copper losses. For general diagram of connections and discussion of the drop method, see fig. 4,864. The current should be kept well within the load current of the transformer to avoid temperature rise during the test. In other words, the resistance of the coil is *the voltage across its terminals divided by the current.*

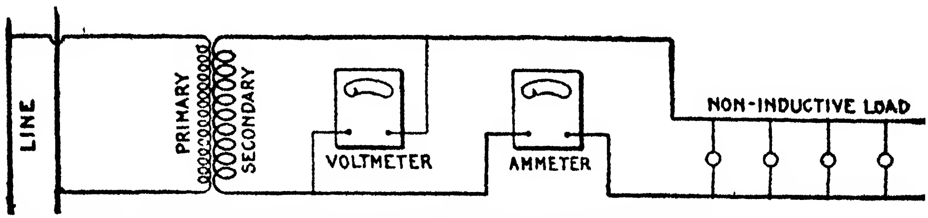


FIG. 4,865.—Temperature test of transformer with non-inductive load.

The resistance of the primary coil can be measured similarly. The copper loss in watts in each coil will then be the product of the resistance and the square of the rated current for that coil.

Temperature Test of Transformer with Non-Inductive Load.—The simplest way of making the test is shown in fig. 4,865. Connect the primary of the transformer to the line as shown, and carry normal secondary load by means of a bank of lamps or other suitable resistance, until full load secondary current is shown by the ammeter in the secondary circuit.

The transformer should then be allowed to run at its rated load for the desired interval of time, temperature readings being made of the oil in its hottest part, and also of the surrounding air.

Where temperatures of the coil rather than temperatures of the oil are desired, it is necessary to uce the resistance method. This is obtained by first carefully measuring the resistance of both pnmary and secondary coils at the temperature of the room, and then, after the transformer has been under heat test for the desired time, disconnect it from the circuit and again measure the resistance of primary and secondary.

For proper method of calculating the temperature rise from resistance measurements, the reader is referred to the standardization rules of the A.I.E.E.

In making resistance measurements of large transformers by the drop method care should be taken to allow both ammeter and volt meter indications to settle down to steady values before readings are taken. This may require several minutes. Each time the current is changed it is necessary in order to obtain check values on resistance measurements, to wait until the current is again settled to its permanent value before taking readings.

All resistance measurements must be taken with great care, as small errors in the measurement of the resistance may make very large errors in the determination of the temperature rise. The method above described is satisfactory for small transformers.

Where large units are to be tested, the cost of current for testing becomes an important item. The "bucking test" as in fig. 4,866, is more economical.

Transformer Temperature Bucking Test.—For this purpose two transformers of the same size and ratio are required. The connections are as shown in fig. 4,866. Full secondary voltage is applied, and rheostats or auxiliary auto-transformers are inserted in the circuit to properly regulate the voltage.

The primaries are connected with one bucking the other, and a voltage equal to twice the impedance voltage of either transformer inserted in the primary circuit. It should be noted that when the secondaries are subjected to the full secondary voltage, a full primary voltage exists across either primary, but with the primaries connected so that the voltage of

one is bucked against the voltage of the other, the resultant voltage in the circuit will be zero.

By applying to the primary circuit twice the impedance voltage of either transformer, full primary and secondary current will circulate through both transformers. On the other hand, by subjecting the secondaries to the full secondary voltage, the iron of the transformer will be magnetized as under its regular operating conditions, and the full iron loss of the transformer introduced. This method permits the operation

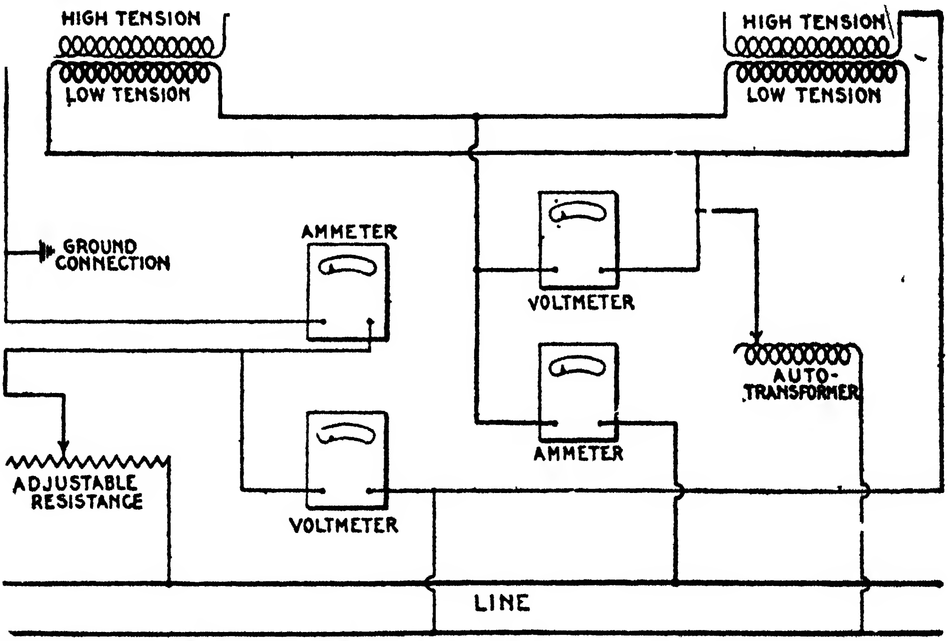


FIG. 4,866.—Transformer temperature "bucking test."

of two transformers under temperature test with their full losses, without taking energy from the line equal to the rated capacity.

Measurements of temperature are taken in exactly the same way as above. This method is successfully employed for making temperature tests on transformers of all sizes.

Transformer Insulation Test.—In applying a 10,000 volt insulation test between the primary and secondary of a

transformer, the testing leads should be disconnected from the transformer under test, and a spark gap introduced as shown in fig. 4,867 with the test needle set at a proper sparking distance for 10,000 volts.

A high resistance should be connected in the secondary before closing its circuit, and the voltage gradually increased by cutting out this secondary resistance until a spark jumps across the spark gap. When the spark jumps across the spark gap, the volt meter reading should be recorded and the testing transformer disconnected. The spark gap should then be increased about 10 per cent., and the high tension leads connected to the transformer under test as indicated in the diagram.

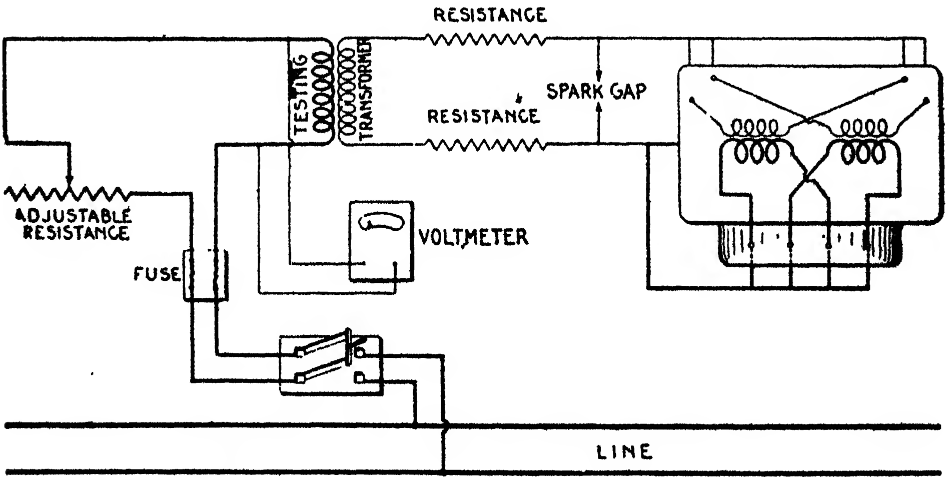
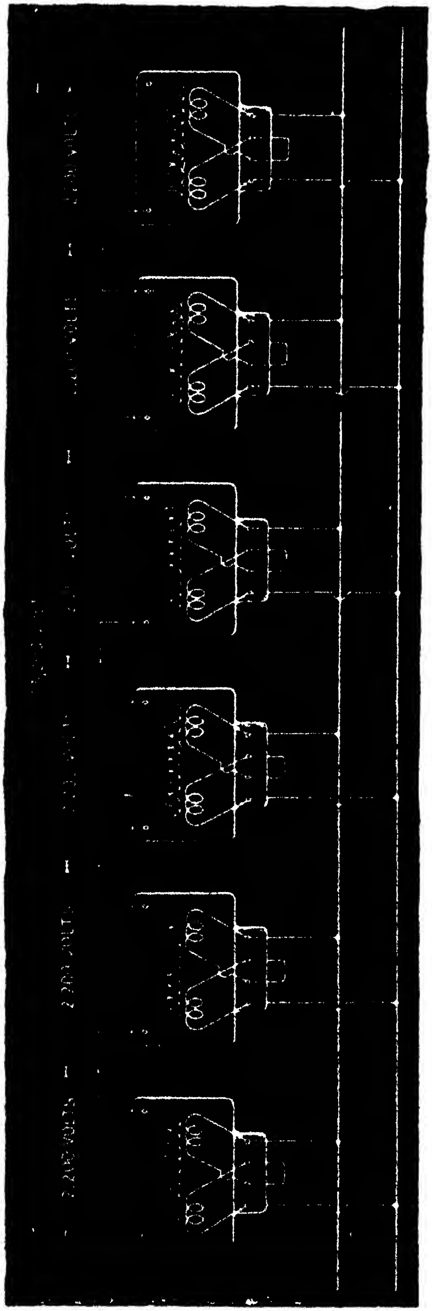


FIG. 4,867.—Transformer insulation test.

In order to equalize the insulation strains, all primary leads should be connected together, all secondary leads not only connected together, but to the core as well. All resistance in the rheostat in the low tension circuit should then be inserted and the switch closed. Gradually cut out secondary resistance until the volt meter shows the same voltage as was recorded previously when the spark jumped across the gap, and apply this voltage to the transformer for one minute.

Insulation tests for a period of over one minute are very unadvisable, as transformers with excellent insulation may be



test as made when a t

seriously damaged by prolonged insulation tests.

The longer the strain to which any insulation is subjected the shorter the subsequent life of the insulation. Also the greater the applied voltage above the actual operating voltage of the apparatus, the shorter the subsequent life of the insulation. In testing small transformers, the spark gap may be omitted and the voltage of the low pressure coil of the testing transformer measured. This multiplied by the ratio of transformation gives the testing voltage.

Transformer Insulation Test without High Tension Transformer.—In this method, a number of standard transformers, connected as shown in fig. 4,868, may be employed, but great care should be taken to have such transformer cases thoroughly insulated from the ground and from one another, in order to minimize the insulation strains in the testing transformers.

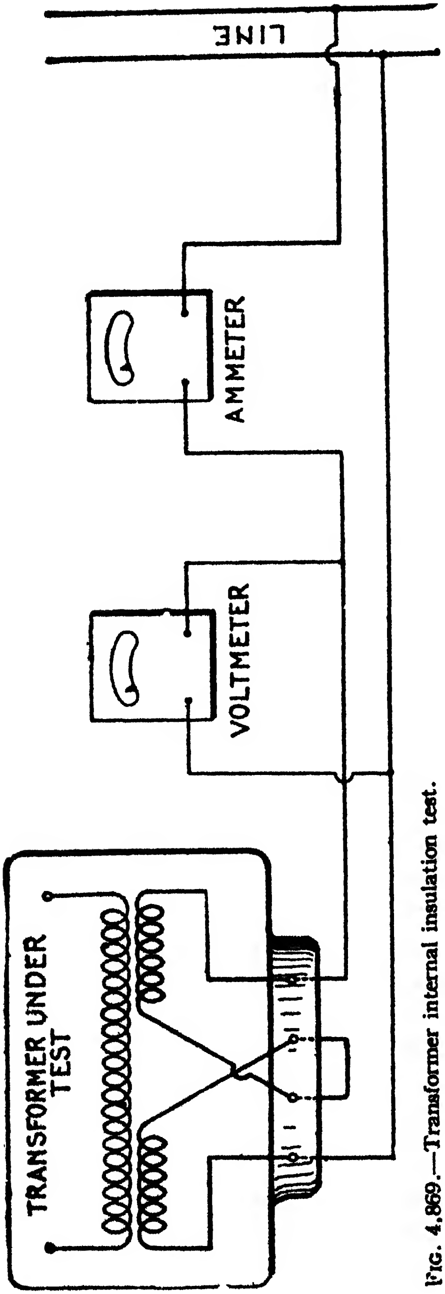


FIG. 4,869.—Transformer internal insulation test.

Care should be taken to insert in the circuit of each testing transformer a fuse, not in excess of the transformer capacity, which will blow, in case of a break down in the apparatus under test.

In testing insulation between secondary and core, disconnect the primary entirely, apply one terminal of the testing transformer to the secondary terminals of the transformer under test, and the other terminal of the testing transformer to the core of the transformer under test. The duration of this test should also not exceed one minute.

Transformer Internal Insulation Test.—This test is sometimes called double normal voltage test, from the fact that most transformers are tested with double normal voltage across their terminals. If either the primary or secondary of the transformer be connected, as shown in fig. 4,869, to some

source of current with voltage double that of the voltage of the transformer under test, the insulation between adjacent turns, and also the insulation between adjacent layers will be subjected to twice the normal operating voltage.

It is good practice to employ high frequency for this test in order to prevent an abnormal current passing through the transformer. Sixty cycle transformers are usually tested on 133 cycle, and 25 cycle transformers on 60 cycle circuits for this double normal voltage test. It is neccssary to insert the resistance in the circuit of the transformer and bring the voltage up gradually, the same as applying other high insulation tests in order to prevent abnormal rises in pressure at the instant of closing the circuit.

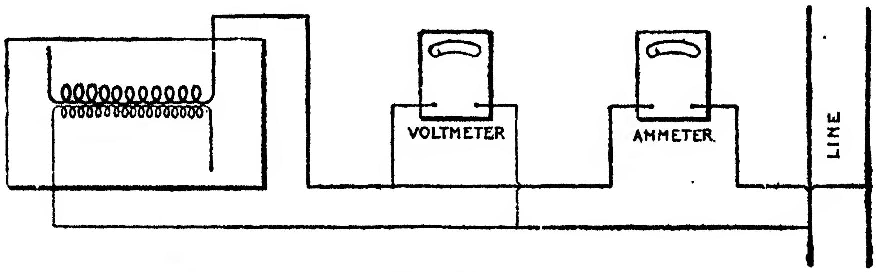


FIG. 4,870.—Transformer insulation resistance test.

Transformer Insulation Resistance Test.—The insulation of a transformer besides being able to resist puncture, due to increased voltage, must also have sufficient resistance to prevent any appreciable amount of current flowing between primary and secondary coils. It is, therefore, sometimes important that the insulation resistance between primary and secondary be measured.

This can be done as shown in fig. 4,870. Great care should be taken to have all wires thoroughly insulated from the ground, and, to have an ammeter placed as near as possible

to the terminals of the transformer under test, in order that current leaking from one side of the line to the other, external to the transformer, may not be measured. Great care is required in making this measurement, in order to obtain consistent results.

Transformer Winding or Ratio Test.—The object of this test is to check the ratio between the primary and the secondary windings. For this purpose a transformer of known ratio is used as a standard. Connect the transformer under test with a standard transformer as shown in fig. 4,871. Leave

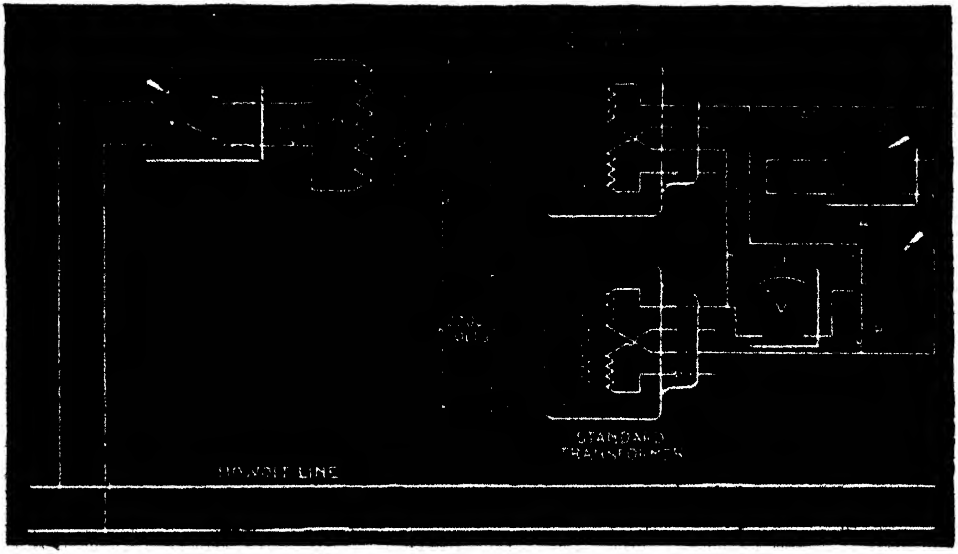


FIG. 4,871.—Transformer winding or ratio test.

switch S_2 open. With the single pole double throw switch in position S,B, the volt meter is thrown across the terminals of the standard transformer. With the switch in position S_1A, the volt meter is thrown across the terminals of the transformer under test. The volt meter should be read with the switch

in each position. If the winding ratio be the same as that of the standard transformer, the two volt meter readings will be identical.

Transformer Polarity Test.—This test, sometimes called a banking test, is of importance. The transformers from any particular manufacturer have the leads brought out in such a manner that a transformer of any size can be connected to primary and secondary lines in a given order without danger of blowing the fuses due to incorrect connections. All manufacturers of transformers, however, do not bank transformers in the same way, so that it is necessary in placing transformers of different makes to test for polarity.

This is done as shown in fig. 4,871. One transformer is selected as a standard and the leads of the second transformer connected as indicated in the diagram.

If the transformers be 1,100–2,200 volts to 110-220, two 110 volt lamps are connected in the secondaries of the transformers as indicated, while the primary of the transformer is connected across the line. In transformers built for two primary and two secondary voltages, it is necessary to test each primary and each secondary. The diagram shows the method of connecting one 2,200 volt coil and one 110 volt coil to the transformer to be tested.

When the primary circuit of the transformer under test is closed, and if the secondary leads of the 110 volt coil under test be brought out of the case properly, the two 110 volt lamps should be brightly illuminated. If, on the other hand, the two 110 volt terminals have been reversed, no current will flow through the lamps.

If these two terminals be found to be brought out correctly, transfer the secondary leads of the transformer under test to the second 110 volt coil. Upon closing the primary circuit, the lamp should again be brightly illuminated. Repeat this process with each of the secondary coils and the other primary coil, and if the lamps show up bright in every case on closing the primary circuit, all leads have been properly brought out.

If on any tests the lamps do not light up brightly, the leads on the transformer must be so changed as to produce the proper banking.

TEST QUESTIONS

1. *What was the criterion of good transformer design in early days?*
2. *Describe transformer copper loss tests by watt meter measurement and impedance.*
3. *Is a watt meter subject to considerable error under low power factor?*
4. *Must the watt meter readings be corrected in copper loss test?*
5. *How do two or more transformers connected in parallel divide the load?*
6. *Describe the resistance measurement by drop method.*
7. *Describe how to test a transformer for temperature on non-inductive load.*
8. *When should the resistance method be used?*
9. *What is the proper method of calculating the temperature rise from resistance measurements?*
10. *What precaution should be taken for making the resistance measurements of large transformers by the drop method?*
11. *Should all resistance measurements be taken with great care?*
12. *What is the "bucking" test?*
13. *When should the bucking test be used?*
14. *Describe in detail transformer temperature bucking test.*
15. *Explain how the transformer insulation test is made.*
16. *Should an insulation test be made for over a period of one minute?*

17. *How should the transformer insulation test be made without high tension transformers?*
18. *Describe transformer internal insulation test.*
19. *What other name is sometimes given to the transformer internal insulation test?*
20. *Explain the method of making the transformer internal insulation test.*
21. *What precaution should be taken in the making of a transformer insulation test?*
22. *Explain how the transformer or ratio test is made.*
23. *How is the transformer polarity test made?*

CHAPTER 94

Motor Testing

There are numerous simple tests of motors which may be easily made requiring only such instruments as volt meters, ammeters and watt meters.

Since the accuracy of a test not only depends upon correct reading, but upon the conditions of the instruments, it should be first ascertained that all the instruments used in making a test are in proper working order.

Accordingly, as pointed out in a preceding chapter (see page 2,855), the instruments should first be tested for accuracy before using them in making a motor test.

It is important to know how to take readings and to know all the practical points relating to the instruments.

Since so much depends upon the proper handling and conditions of the instruments, it is suggested that the reader carefully study the preceding chapter before testing motors.

How to Connect Instruments for Power Measurement.— There are several ways of connecting an ammeter, volt meter and watt meter in the circuit for the measurement of power. A few of the methods are here discussed and illustrated in figs. 4,859 to 4,862.

With some of the connections it is necessary to correct the readings of the watt meter for the losses in the coil or coils, of the watt meter, or for losses in the ammeter or volt meter. This is necessary since the instruments may be so connected that the watt meter not only measures the load but includes in its indications some of the instrument losses.

If the load measured be small or considerable accuracy be required, these instrument losses may be calculated as follows:

Loss in pressure coil is

$$E^2 \div R,$$

in which,

E = voltage at the terminals of the pressure coil.

R = its resistance in ohms.

Loss in current coil is I^2R, in which

I = current in amperes.

R = resistance of the current coil in ohms.

In general let:

E_v = voltage across terminals of the volt meter.

E_w = voltage across the terminals of the pressure coil of the watt meter.

I_w = current through current coil of watt meter.

I_a = current through current coil of ammeter.

R_v = resistance of pressure coil of volt meter.

R_w = resistance of pressure coil of watt meter.

R^1_w = resistance of current coil of watt meter.

R_a = resistance of current coil of ammeter.

P_w = watt meter reading.

P = power to be measured.

With this notation the losses in the various coils will be as follows:

$E^2_v \div R_v$ = loss in watts in pressure coil of volt meter.

$E^2_w \div R_w$ = loss in watts in pressure coil of watt meter.

$I^2_w R^1_w$ = loss in watts in current coil of watt meter.

$I^2_a R_a$ = loss in watts in current coil of ammeter.

If connections be made as in fig. 4,859, the correct power of the circuit will be

$$P_w - (E^2_v \div R_v + E^2_w \div R_w) \text{ in watts and } E_v = E_w.$$

In fig. 4,860,

$$P = P_w - E^2_w \div R_w, \text{ in watts}$$

In fig. 4,861,

$$P = P_w - I^2_w R^1_w \text{ in watts}$$

or the correct power is *the watt meter reading minus the loss in the current coil of the watt meter.*

In fig. 4,862,

$$P = P_w - (E^2_w \div R_w + I^2_a R_a) \text{ in watts}$$

The usual method of connection is either as in fig. 4,859 or fig. 4,860.

In either case the current reading is that of the load plus the current in

the pressure coils of the volt meter and watt meter. Unless the current being measured, however, be very small, or extreme accuracy be desired, it is unnecessary to correct ammeter readings.

In fig. 4,860, a small error is introduced due to the fact that the actual voltage applied to the load is that given by the volt meter minus the small drop in voltage through the current coil of the watt meter.

If an accurate measure of the current in connection with the power consumed by the load be required, the connections shown in fig. 4,862 are used, and if extreme accuracy be

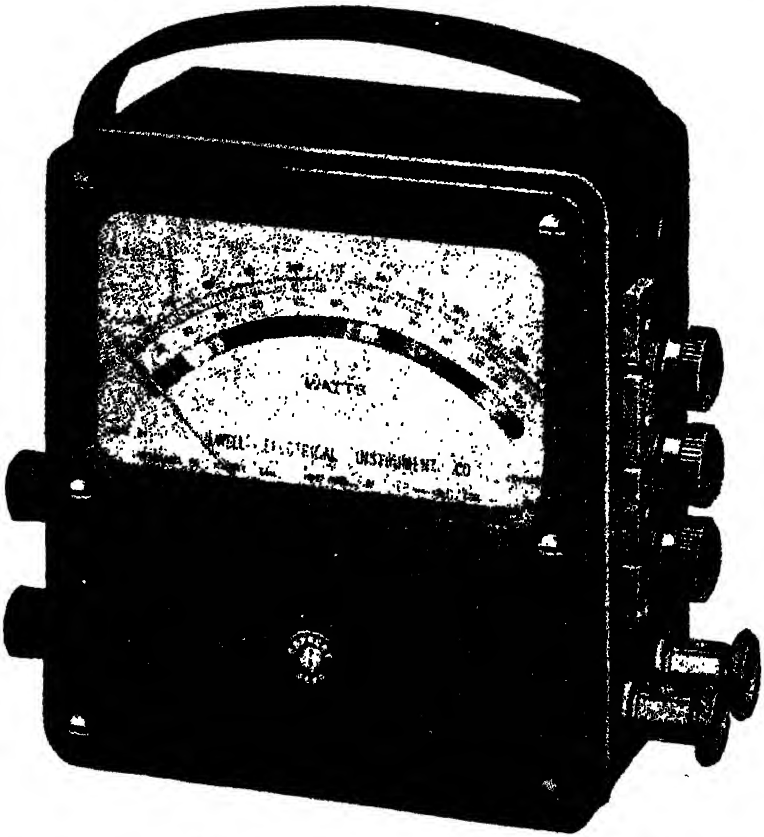


FIG. 4,872.—Jewel two scale single phase portable testing watt meter. The moving element is effectively shielded from outside magnetic fields by a special laminated construction. The method of obtaining series and parallel readings is such as to avoid metal links.

required, the watt meter reading is reduced by the losses in the ammeter and in the pressure coil of the watt meter.

The loss in the pressure coil of a watt meter or volt meter may be as high as 12 or 15 watts at 220 volts.

The loss in the current coil of a watt meter with 10 amperes flowing through it may be 6 or 8 watts. It can be easily seen that if the core or copper losses of small transformers are being measured, it is quite necessary to correct all watt meter readings for instrument losses.

In measuring the losses of a 25 or 50 *h.p.* induction motor, the instrument losses may be neglected.

WATTMETER ERROR FOR A LOAD OF 1,000 VOLT-AMPERES

(For a lag of 1 degree in the pressure coil)

Power factor	True watts	Error	Error of indication in per cent. of true value
1.	1,000	.3	0.03
.9	900	7.6	0.85
.8	800	10.5	1.31
.7	700	12.5	1.78
.6	600	13.9	2.32
.5	500	15.1	3.02
.4	400	15.9	3.98
.3	300	16.6	5.54
.2	200	17.1	8.55
.1	100	17.3	1.73

NOTE.—In the *iron vane type instrument* when used as a watt meter, the current of the series coil always remains in perfect phase with the current of the circuit, provided series transformers be not introduced. The error, then, is entirely due to the lag of the current in the pressure coil, and this error in high power factor is exceedingly small, increasing as the power factor decreases. In the above table it should be noted that the value of the error as distinguished from the per cent. of error, instead of indefinitely increasing as the power factor diminishes, rapidly attains a maximum value which is less than 2 per cent. of the power delivered under the same current and without inductance. It should also be noted that the above tabulation is on the assumption of a lag of 1 degree in the pressure coil. The actual lag in Wagner instruments for instance, is approximately .085 of a degree, and the error due to the lag of the pressure coil in Wagner instruments is, therefore, proportionally reduced from the figures shown in the above tabulation.

Connections are seldom used which make it necessary to correct for the losses in the current coils of either ammeter or watt meter, as the losses vary with the change in the current.

On the other hand, the voltages generally used are fairly constant at 110 or 220, and when the losses of the pressure coils at these voltages have once been calculated, the necessary instrument correction can be readily made.

Single Phase Motor Test.—In this method of measuring the input of a single phase motor of any type, the ammeter, volt meter and watt meter are connected as shown in fig. 4,873.

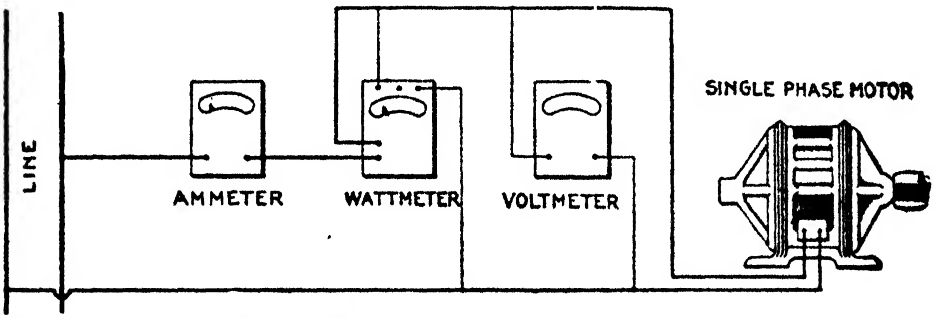


FIG. 4,873.—Single phase motor test.

The ammeter measures the current flowing through the motor, the volt meter the pressure across the terminals of the motor, and the watt meter the total power input to the motor. With the connections as shown the watt meter would also measure the slight losses in the volt meter and the pressure coil of the watt meter, but for motors of ¼ *h.p.* and larger, this loss is so small that it may be neglected.

The power factor may be calculated by dividing the true watts as indicated by the watt meter, by the product of the volts and amperes.

Three Phase Motor Tests.—There are several methods of testing three phase motors and known as

1. Volt meter and ammeter method;
2. Two watt meter method;
3. Polyphase watt meter method;
4. One watt meter method;
5. One watt meter and Y box method, etc.

These methods will now be given.

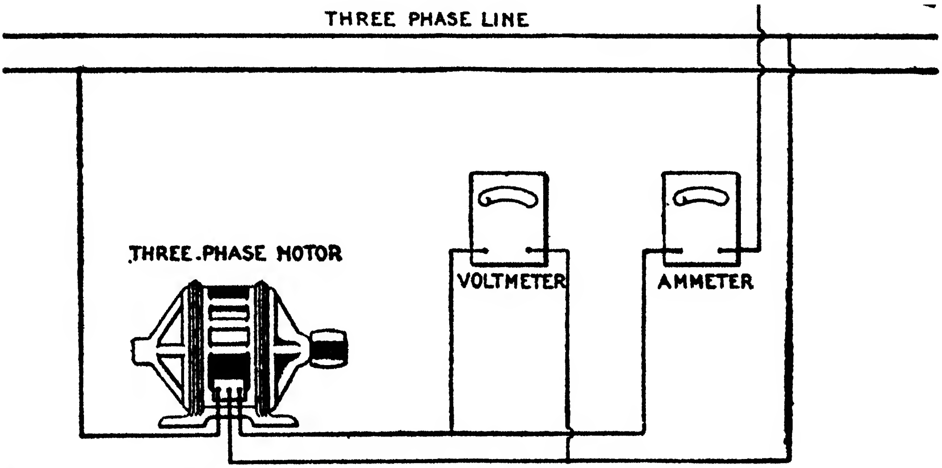


Fig. 4,874.—Three phase motor test; ***volt meter and ammeter method.***

Volt Meter and Ammeter Method.—In this method of testing a three phase motor, if it be desired to determine the approximate load on a three phase motor, this may be done by means of the connections as shown in fig. 4,874, and the current through one of the three lines and the voltage across the phase measured.

If the voltage be approximately the rated voltage of the motor and the amperes the rated current of the motor (as noted on the name plate) it may be assumed that the motor is carrying approximately full load.

If, on the other hand, the amperes show much in excess of full load rating, the motor is carrying an overload. The heat generated in the copper varies as the square of the current. That generated in the iron varies anywhere from the 1.6 power to the square.

This method is very convenient if a watt meter be not available, although it is, of course, of no value for the determination of the efficiency or power factor of the apparatus.

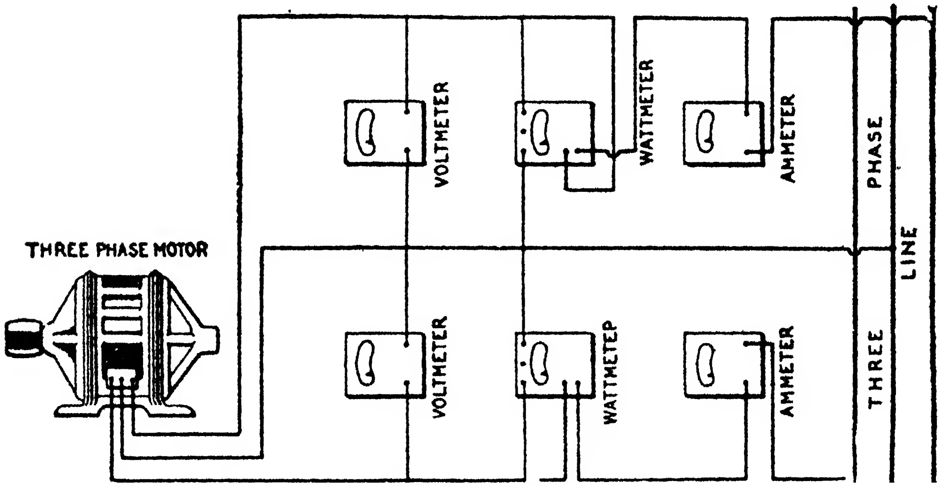


Fig. 4,875.—Three phase motor test; *two watt meter method.*

This method gives fairly accurate results, providing the load on the three phases of the motor be fairly well balanced. If there be much difference, however, in the voltage of the three phases, the ammeter should be switched from one circuit to another, and the current measured in each phase. If the motor be very lightly loaded and the voltage of the different phases vary by 2 or 3 per cent., the current in the three legs of the circuit will vary 20 to 30 per cent.

Two Watt Meter Method.—If an accurate test of a three phase motor be required, it is necessary to use the method as shown in fig. 4,875. Assume the motor to be loaded with a

brake so that its output can be determined. This method gives correct results even with considerable unbalancing in the voltages of the three phases.

With the connections as shown, the sum of the two watt meter readings gives the total power in the circuit. Neither meter by itself measures the power in any one of the three phases. In fact, with light load one of the meters will probably give a negative reading, and it will then be necessary to either reverse its current or pressure leads in order that the deflection may be noted. In such cases the algebraic sum of the two readings must be taken. In other words, if one read plus 500 watts and the other, minus 300 watts, the total power in the circuit will be 500 minus 300, or 200 watts.

As the load comes on, the readings of the instrument which gave the negative deflection will decrease until the reading drops to zero, and it will then be necessary to again reverse the pressure leads on this watt meter. Thereafter the readings of both instruments will be positive, and the numerical sum of the two should be taken as the measurement of the load.

If one set of the instruments be removed from the circuit, the reading of the remaining watt meter will have no meaning. As stated above, it will not indicate the power under these conditions in any one phase of the circuit. The power factor is obtained by dividing the actual watts input by the product of the average of the volt meter readings and the average of the current readings $\times$ 1.73.

Polyphase Watt Meter Method.—This method of testing a three phase motor is identical with the two watt meter method shown in fig. 4,875, except that the watt meter itself combines the movement of the two watt meters. Otherwise the method of taking the measurements is identical. If the power factor be known to be less than 50 per cent., connect one movement so as to give a positive deflection; then disconnect movement one and connect movement two so as to give a positive deflection. Then reverse either the pressure or current leads of the movement, giving the smaller deflection, leaving the remaining movement with the original connections.

The readings now obtained will be the correct total watts delivered to the motor. If the power factor be known to be over 50 per cent., the same methods should be employed, except that both movements should be independently connected to give positive readings.

An unloaded induction motor has a power factor of less than 50 per cent., and may, therefore, be used as above for determining the correct connections. For a better understanding of the reasons for the above method of procedure, the explanation of the two watt meter method, fig. 4,875, should be read.

The power factor may be calculated as explained under fig. 4,875. Connect as shown in fig. 4,875.

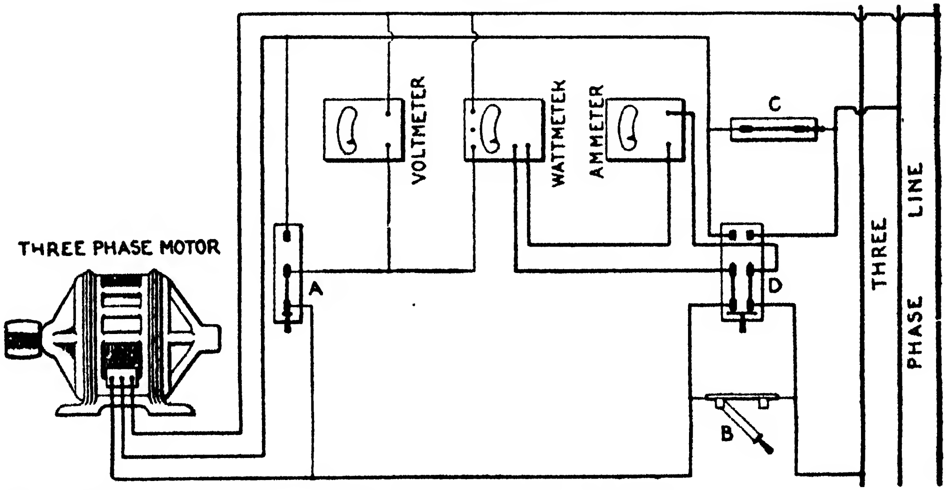


FIG. 4,876.—Three phase motor test; *one watt meter method.*

The following check on connections may be made. Let the polyphase induction motor run idle, that is, with no load. The motor will then operate with a power factor less than 50 per cent. The polyphase meter should give a positive indication, but if each movement be tried separately one will be found to give a negative reading, the other movement will give a positive reading. This can be done by disconnecting one of the pressure leads from the binding post of one movement. When the power factor is above 50 per cent., then both movements will give positive deflection.

One Watt Meter Method.—This method is equivalent to

the two watt meter method with the following difference. A single volt meter (as shown in fig. 4,876) with a switch A, can be used to connect the volt meter across either one of the two phases. Three switches B,C and D, are employed for changing the connection of the ammeter and watt meter in either one of the two lines.

With the switches B and D, in the position shown, the ammeter and watt meter series coils are connected in the left hand line. The switch C, must be closed under these conditions in order to have the middle line closed.

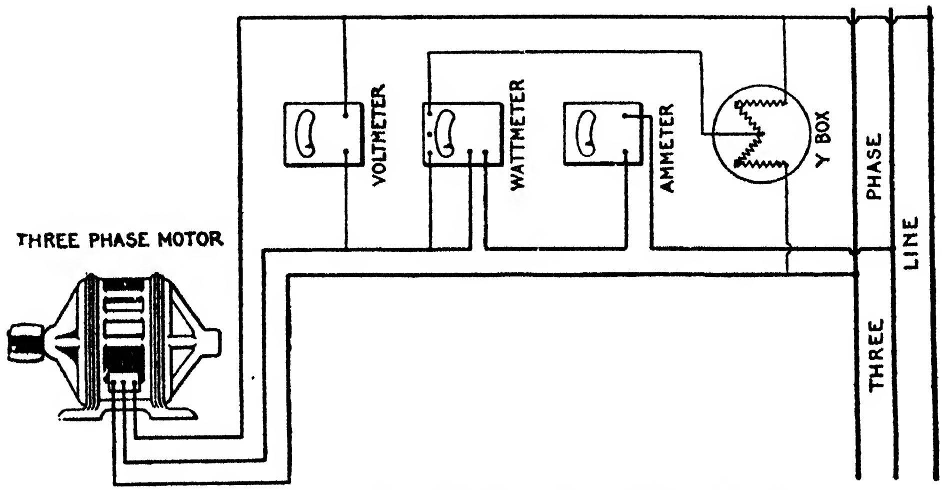


FIG. 4,877.—Three phase motor test; *one watt meter and Y box method.*

Another reading should then be taken before any change of load has occurred, with switch A, thrown to the right, switch B, closed, switch D, thrown to the right and switch C, opened. The ammeter and the current coil of the watt meter will then be connected to the middle line of the motor. In order to prevent any interruption of the circuit, the switches B,D and C, should be operated in the order given above.

With very light load on the motor the watt meter will probably give a negative deflection in one phase or the other, and it will be necessary to reverse its connections before taking the readings. For this purpose a double pole, double throw switch is sometimes inserted in the circuit of the pressure coil of the watt meter so that the indications can be reversed without disturbing any of the connections.

It is suggested, before undertaking this test, that the instructions for test by the two watt meter and by the polyphase watt meter methods be read.

One Watt Meter with Y Box Method.—This method, as shown in fig. 4,877, is of service only provided the voltages of the three phases be the same.

A slight variation of the voltage of the different phases may cause a very large error in the readings of the watt meter, and inasmuch as the voltage of all commercial three phase circuits is more or less unbalanced,

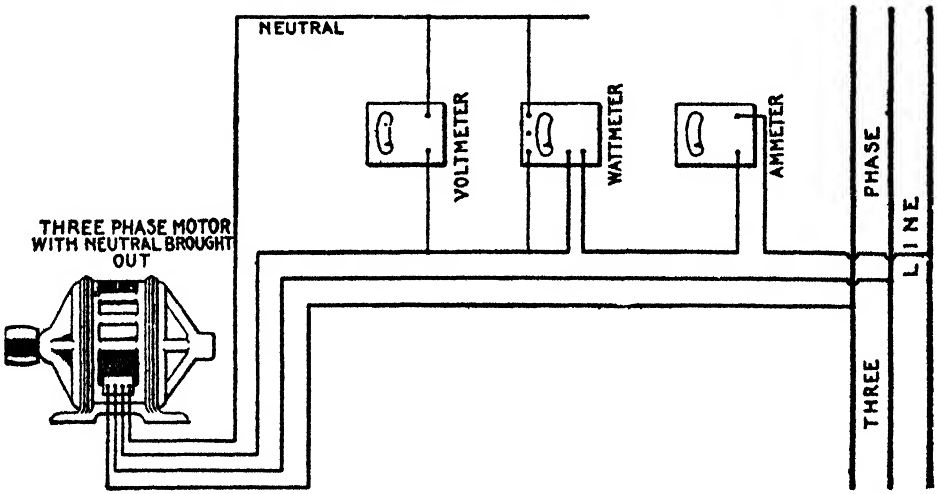


Fig. 4,878.—Test of three phase motor with neutral brought out; *one watt meter method.*

this method is not to be recommended for motor testing. With balanced voltage in all three phases, the power is that indicated by the watt meter, multiplied by three. Power factor may be calculated as before.

Test of Three Phase Motor with Neutral Brought Out.—This test as shown in fig. 4,878, employs a single watt meter. Some star connected motors have the connection brought out from the neutral of the winding. In this case the circuit may be connected, as shown in fig. 4,878.

The volt meter now measures voltage between the neutral and one of the lines, and the watt meter the power in one of the three phases of the motor. Therefore, the total power taken by the motor will be three times the watt meter readings. By this method, just as accurate results can be obtained as with the two watt meter method.

The power factor will be *the indicated watts divided by the product of the indicated amperes and volts.*

Temperature Test of a Large Three Phase Induction Motor. —In this method as shown in fig. 4,879, two motors, prefer-

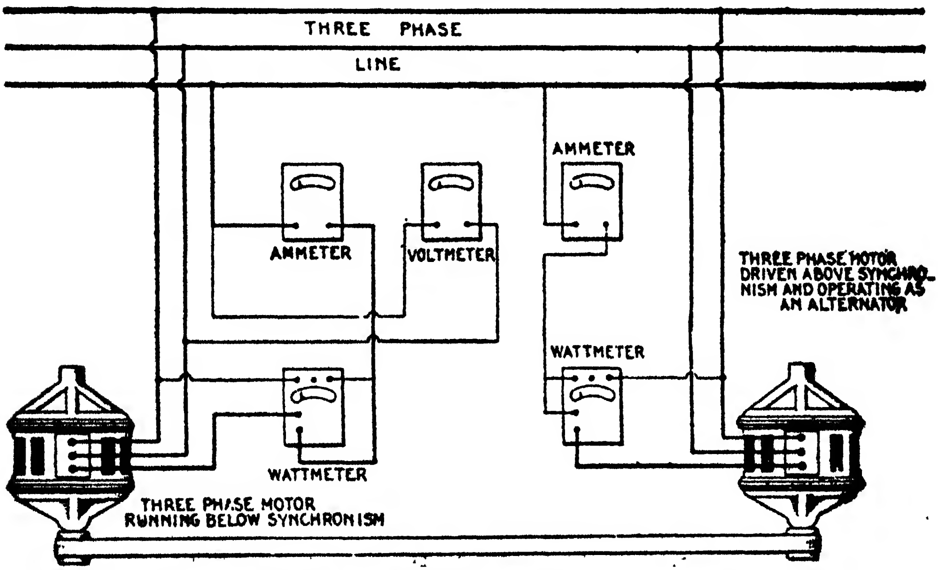


FIG. 4,879.—Temperature test of a large three phase induction motor.

ably of the same size and type, are required. One is driven as a motor and runs slightly below synchronism, due to its slip when operating with load. This motor is belted to a second machine. If the pulley of the second machine be smaller than the pulley of the first machine, the second machine will then operate as an alternator and will return to the line as much power as the first motor draws from the line, less the losses of the second machine.

By properly selecting the ratio of pulleys, the first machine can be caused to draw full load current and full load energy from the line. In this way, the total energy consumed is equivalent to the total of the losses of both machines, which is approximately twice the losses of a single machine.

Fig. 4,879 shows the connection of the watt meters, without necessary switches, for reading the total energy by two watt meter method. Detailed connection of the watt meter is shown in fig. 4,876.

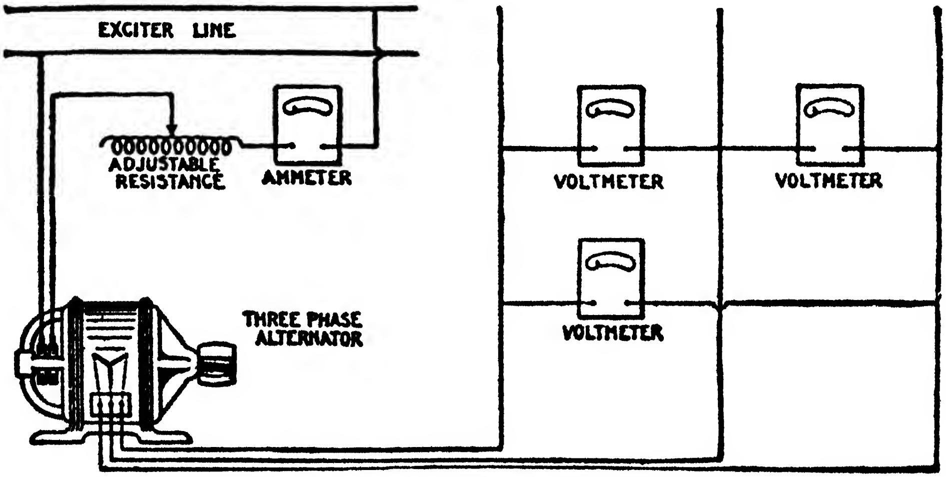


FIG. 4,880.—Alternator excitation or magnetization curve test.

It is usual, in making temperature tests, to insert one or more thermometers in what is supposed to be the hottest part of the winding, one on the surface of the laminæ and one in the air duct between the iron laminæ. The test should be continued until the difference in temperature between any part of the motor and the air reaches a steady value. The motor should then be stopped and the temperature of the armature also measured.

NOTE.—*Temperature tests of small induction motors* are usually made on small induction motors by belting the motor to a generator and loading the generator with a lamp bank or resistance until the motor input is equal to the full load. If, however, the motor be of considerable size, such that the cost of power becomes a considerable item in the cost of testing, the method shown in fig. 4,879 may be used.

NOTE.—*For the approved method* of taking temperature readings and interpreting results, see *Standardization Rules* of the *A.I.E.E.*

Alternator Excitation or Magnetization Curve Test.—The object of this test is to determine the change of the armature voltage due to the variation of the field current when the external circuit is kept open. As shown in fig. 4,880, the field circuit is connected with an ammeter and an adjustable resistance in series with a direct current source of supply.

The adjustable resistance is varied, and readings of the volt meter

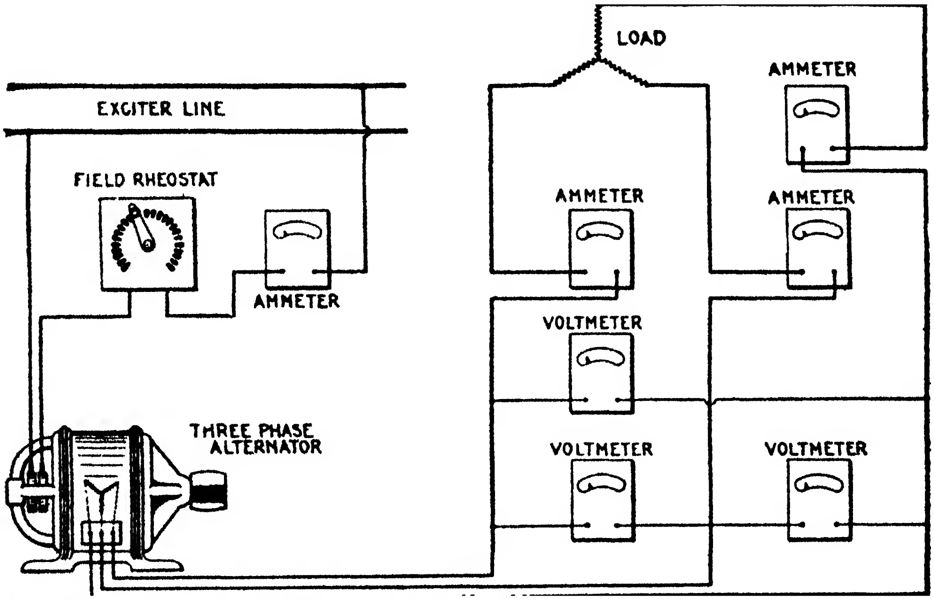


FIG. 4,881.—Three phase alternator synchronous impedance test.

across the armature, and of the ammeter, are recorded. The speed of the generator must be kept constant, preferably at the speed which is given on the name plate. The excitation or magnetization curve of the machine is obtained by plotting the current and the voltage.

Three Phase Alternator Synchronous Impedance Test.—In determining the regulation of an alternator, it is necessary to obtain what is called the *synchronous impedance* of the machine.

To obtain this, the field is connected, as shown in fig. 4,881. Volt meters are removed and the armature short circuited with the ammeters in circuit. The field current is then varied, the armature driven at synchronous speed, and the armature current measured by the ammeters in circuit. The relation between field and armature amperes is then plotted.

The combination of the results of this test, with those obtained from the excitation or magnetization curve test shown in fig. 4,880, are used in the determination of the regulation of an alternator.

Engineers differ widely in the application of the above to the determination of regulation, and employ many empirical formulæ and constants for different lines of design.

Three Phase Alternator Load Test.—By means of the connection shown in fig. 4,881, readings of armature current and field amperes can be obtained for any desired load.

The field current can be varied also so as to maintain constant armature voltage irrespective of load; or the field current may be kept constant and the armature voltage allowed to vary as the load increases.

The connections may also be used to make a temperature test on the alternator by loading it with an artificial load.

In some cases after the alternator is installed the connection may be used to make a temperature test, using the actual commercial load the alternator is furnishing.

Three Phase Alternator or Synchronous Motor Temperature Test.—In this test, as shown in fig. 4,882, two alternators or synchronous motors of same size and type are used, and are belted together, one to be driven as a synchronous motor and the other as an alternator. The method employed is to synchronize the synchronous motor with the alternator or alternators on the three phase circuit, and then connect to the

line by means of a three pole single throw switch. The alternator is then similarly synchronized with the alternator of the three phase circuit and thrown onto the line.

By varying the field of the alternator it can be made to carry approximately full load, and the motor will then be also approximately fully loaded. The usual method is to have the motor carry slightly in excess of full load, and the alternator slightly less than full load. Under these conditions the motor will run a little warmer than it should with normal load, while the alternator will run slightly cooler.

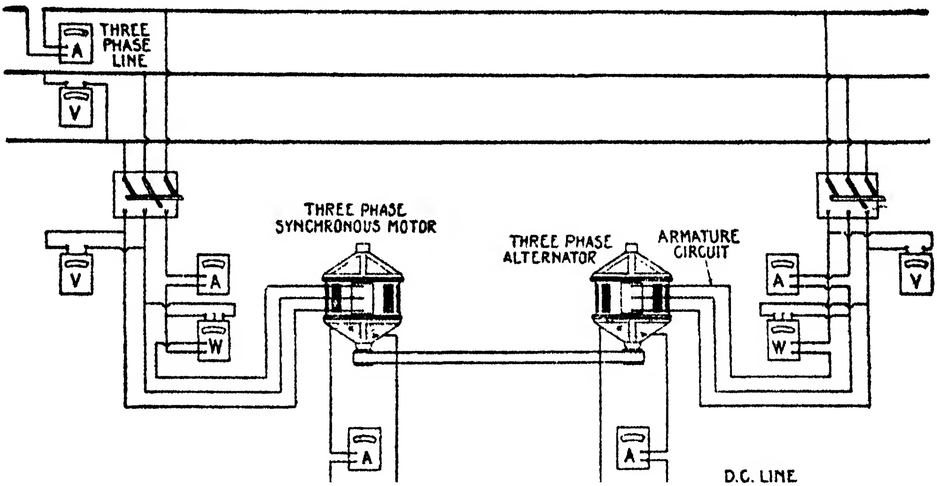


FIG. 4,882.—Three phase alternator or synchronous motor temperature test; *first method.*

Temperature measurements are made in the same way as discussed under three phase motors.

The necessary ammeters, volt meters and watt meters for adjusting the loads on the motors and alternator are shown in above figure. If pulleys be of sufficient size to transmit the full load, with, say one per cent. slip, the pulley on the motor should be one per cent. larger in diameter than

the pulley on the alternator, so as to enable the alternator to remain in synchronism and at the same time deliver power to the circuit.

With very large machines under test, it is inadvisable to use the above method as it is sometimes difficult to so adjust the pulleys and belt tension that the belt slip will be just right to make up for the difference in diameter of the pulleys, and very violent flapping of the belt results. To meet such cases, various other methods have been devised. One which gives consistent results is described as follows:

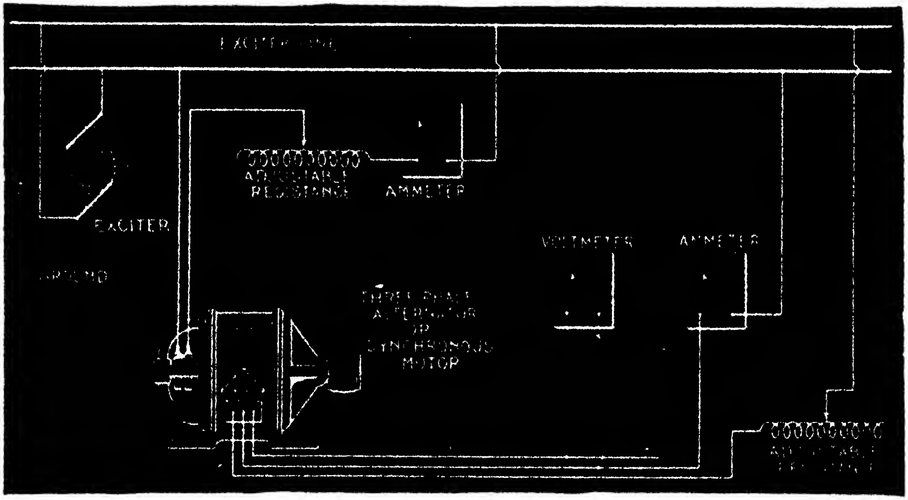


Fig. 4,883.—Three phase alternator or synchronous motor temperature test; *second method.*

In this method, supply the field with normal field current. The armature is connected in open delta as shown in fig. 4,883, and full load current sent through it from an external source of direct current, care being taken to ground one terminal of the dynamo so as to avoid danger of shock due to the voltage on the armature winding. The field is then driven at synchronous speed.

If the armature be designed to be connected star for 2,300 volts, the voltage generated in each leg of the delta will be 1,330 volts, and unless one leg of the dynamo be grounded, the tester might receive a severe shock by coming in contact with the direct current circuit. The insulation of the dynamo would also be subjected to abnormal strain unless one terminal were grounded. By the above method the field is subjected to its full copper loss and the armature to full copper loss and core loss. Temperature readings are taken as per standardization rules of the A.I.E.E.

This method may also be used with satisfactory results on large three phase motors of the wound rotor type. If the alternator pressure be above 600 volts, a pressure transformer should be used in connection with the volt meter.

TEST QUESTIONS

1. *Draw diagrams showing the various ways of connecting instruments for power measurements.*
2. *How are instrument losses calculated for small loads?*
3. *In what kind of test may the instrument losses be neglected?*
4. *When an iron vane type instrument is used as a watt meter, explain the action of the current in the series coil.*

Explain in detail the method and calculations employed in making the following tests:

5. *Single phase motor test.*
6. *Three phase motor test.*
7. *Volt meter and ammeter method.*
8. *Two watt meter method.*
9. *Polyphase watt meter method.*
10. *One watt meter with Y box method.*
11. *Test of three phase motor with neutral brought out.*
12. *Temperature test of a large three phase induction motor.*
13. *Temperature test of small induction motors.*
14. *Approved method of taking readings.*
15. *Alternator excitation or magnetization curve test.*

16. *Three phase alternator synchronous impedance test.*
17. *Three phase alternator load test.*
18. *Three phase alternator or synchronous motor temperature test.*

Useful Information

To find the circumference of a circle, multiply the diameter by 3.1416.

To find the diameter of a circle, multiply the circumference by .31831.

To find the area of a circle, multiply the square of the diameter by .7854.

The radius of a circle $\times$ 6.283185 = the circumference.

The square of the circumference of a circle $\times$ .07958 = the area.

Half the circumference of a circle $\times$ half its diameter = the area.

The circumference of a circle $\times$ .159155 = the radius.

The square root of the area of a circle $\times$ .56419 = the radius.

The square root of the area of a circle $\times$ 1.12838 = the diameter.

To find the diameter of a circle equal in area to a given square, multiply a side of the square by 1.12838.

To find the side of a square equal in area to a given circle, multiply the diameter by .8862.

To find the side of a square inscribed in a circle, multiply the diameter by .7071.

To find the side of a hexagon inscribed in a circle, multiply the diameter of the circle by .500.

To find the diameter of a circle inscribed in a hexagon, multiply a side of the hexagon by 1.7321.

To find the side of an equilateral triangle inscribed in a circle, multiply the diameter of the circle by .866.

To find the diameter of a circle inscribed in an equilateral triangle, multiply a side of the triangle by .57735.

To find the area of the surface of a ball (sphere), multiply the square of the diameter by 3.1416.

To find the volume of a ball (sphere), multiply the cube of the diameter by .5236.

Doubling the diameter of a pipe increases its capacity four times.

To find the pressure in pounds per square inch at the base of a column of water, multiply the height of the column in feet by .433.

A gallon of water (U. S. Standard) weighs 8.336 pounds and contains 231 cubic inches. A cubic foot of water contains 7½ gallons, 1728 cubic inches, and weighs 62.425 pounds at a temperature of about 39° F. These weights change slightly above and below this temperature.

In accordance with the standard practice approved by the American Standards Association, the ratio 25.4 mm = 1 inch is used for converting millimeters to inches. This factor varies only two millionths of an inch from the more exact factor 25.40005 mm, a difference so small as to be negligible for industrial length measurements.

Metric Measures

The metric unit of length is the meter = 39.37 inches.
The metric unit of weight is the gram = 15.432 grains.
The following prefixes are used for sub-divisions and multiples: Milli = $\frac{1}{1000}$, Centi = $\frac{1}{100}$, Deci = $\frac{1}{10}$, Deca = 10, Hecto = 100, Kilo = 1000, Myria = 10,000.

Metric and English Equivalent Measures

MEASURES OF LENGTH

Metric	*English*
1 meter	39.37 inches, or 3.28083 feet, or 1.09361 yards
.3048 meter	1 foot
1 centimeter	.3937 inch
2.54 centimeters	1 inch
1 millimeter	.03937 inch, or nearly 1-25 inch
25.4 millimeters	1 inch
1 kilometer	1093.61 yards, or 0.62137 mile

MEASURES OF WEIGHT

Metric		*English*
1 gram	=	15.432 grains
.0648 gram	=	1 grain
28.35 grams	=	1 ounce avoirdupois
1 kilogram	=	2.2046 pounds
.4536 kilogram	=	1 pound
1 metric ton 1000 kilograms	=	.9842 ton of 2240 pounds 19.68 cwt. 2204.6 pounds
1.016 metric tons 1016 kilograms		1 ton of 2240 pounds

MEASURES OF CAPACITY

Metric	*English*
1 liter (= 1 cubic decimeter)	61.023 cubic inches .03531 cubic foot .2642 gal. (American) 2.202 lbs. of water at 62° F.
28.317 liters	1 cubic foot
3.785 liters	1 gallon (American)
4.543 liters	1 gallon (Imperial)

English Conversion Table

Length

Inches	×	.0833	=	feet
Inches	×	.02778	=	yards
Inches	×	.00001578	=	miles
Feet	×	.3333	=	yards
Feet	×	.0001894	=	miles
Yards	×	36.00	=	inches
Yards	×	3.00	=	feet
Yards	×	.0005681	=	miles
Miles	×	63360.00	=	inches
Miles	×	5280.00	=	feet
Miles	×	1760.00	=	yards
Circumference of circle	×	.3188	=	diameter
Diameter of circle	×	3.1416	=	circumference

Area

Square inches	×	.00694	=	square feet
Square inches	×	.0007716	=	square yards
Square feet	×	144.00	=	square inches
Square feet	×	.11111	=	square yards
Square yards	×	1296.00	=	square inches
Square yards	×	9.00	=	square feet
Dia. of circle squared	×	.7854	=	area
Dia. of sphere squared	×	3.1416	=	surface

Volume

Cubic inches	×	.0005787	=	cubic feet
Cubic inches	×	.00002143	=	cubic yards
Cubic inches	×	.004329	=	U. S. gallons
Cubic feet	×	1728.00	=	cubic inches
Cubic feet	×	.03704	=	cubic yards
Cubic feet	×	7.4805	=	U. S. gallons
Cubic yards	×	46656.00	=	cubic inches
Cubic yards	×	27.00	=	cubic feet
Dia. of sphere cubed	×	.5236	=	volume

Weight

Grains (avoirdupois)	×	.002286	=	ounces
Ounces (avoirdupois)	×	.0625	=	pounds
Ounces (avoirdupois)	×	.00003125	=	tons
Pounds (avoirdupois)	×	16.00	=	ounces
Pounds (avoirdupois)	×	.01	=	hundredweight
Pounds (avoirdupois)	×	.0005	=	tons
Tons (avoirdupois)	×	32000 00	=	ounces
Tons (avoirdupois)	×	2000.00	=	pounds

English Conversion Table

Energy

Horsepower	×	33000.	= ft.-lbs. per min.
B. t. u.	×	778.26	= ft.-lbs.
Ton of refrigeration	×	200.	= B. t. u. per min.

Pressure

Lbs. per sq. in.	×	2.31	= ft. of water (60°F.)
Ft .of water (60°F.)	×	.433	= lbs. per sq. in.
Ins. of water (60°F.)	×	.0361	= lbs. per sq. in.
Lbs. per sq. in.	×	27.70	= ins. of water (60°F.)
Lbs. per sq. in.	×	2.041	= ins. of Hg. (60°F.)
Ins. of Hg (60°F.)	×	.490	= lbs. per sq. in.

Power

Horsepower	×	746.	= watts
Watts	×	.001341	= horsepower
Horsepower	×	42.4	= B. t. u. per min.

Water Factors (at point of greatest density—39.2°F)

Miners inch (of water)	×	8.976	= U. S .gals. per min.
Cubic inches (of water)	×	.57798	= ounces
Cubic inches (of water)	×	.036124	= pounds
Cubic inches (of water)	×	.004329	= U. S. gallons
Cubic inches (of water)	×	.003607	= English gallons
Cubic feet (of water)	×	62.425	= pounds
Cubic feet (of water)	×	.03121	= tons
Cubic feet (of water)	×	7.4805	= U. S. gallons
Cubic feet (of water)	×	6.232	= English gallons
Cubic foot of ice	×	57.2	= pounds
Ounces (of water)	×	1.73	= cubic inches
Pounds (of water)	×	26.68	= cubic inches
Pounds (of water)	×	.01602	= cubic feet
Pounds (of water)	×	.1198	= U. S. gallons
Pounds (of water)	×	.0998	= English gallons
Tons (of water)	×	32.04	= cubic feet
Tons (of water)	×	239.6	= U. S. gallons
Tons (of water)	×	199.6	= English gallons
U. S. gallons	×	231.00	= cubic inches
U. S. gallons	×	.13368	= cubic feet
U. S. gallons	×	8.345	= pounds
U. S. gallons	×	.8327	= English gallons
U. S. gallons	×	3.785	= liters
English gallons (Imperial)	×	277.41	= cubic inches
English gallons (Imperial)	×	.1605	= cubic feet
English gallons (Imperial)	×	10.02	= pounds
English gallons (Imperial)	×	1.201	= U. S. gallons
English gallons (Imperial)	×	4.546	= liters

Metric Conversion Table

Length			
Millimeters	×	.03937	= inches
Millimeters	÷	25.4	= inches
Centimeters	×	.3937	= inches
Centimeters	÷	2.54	= inches
Meters	×	39.37	= inches (Act. Cong.)
Meters	×	3.281	= feet
Meters	×	1.0936	= yards
Kilometers	×	.6214	= miles
Kilometers	÷	1.6093	= miles
Kilometers	×	3280.8	= feet
Area			
Sq. Millimeters	×	.00155	= sq. in.
Sq. Millimeters	÷	645.2	= sq. in.
Sq. Centimeters	×	.155	= sq. in.
Sq. Centimeters	÷	6.452	= sq. in.
Sq. Meters	×	10.764	= sq. ft.
Sq. Kilometers	×	247.1	= acres
Hectares	×	2.471	= acres
Volume			
Cu. Centimeters	÷	16.387	= cu. in.
Cu. Centimeters	÷	3.69	= fl. drs. (U.S.P.)
Cu. Centimeters	÷	29.57	= fl. oz. (U.S.P.)
Cu. Meters	×	35.314	= cu. ft.
Cu. Meters	×	1.308	= cu. yards
Cu. Meters	×	264.2	= gals. (231 cu. in.)
Litres	×	61.023	= cu. in. (Act. Cong.)
Litres	×	33.82	= fl. oz. (U.S.P.)
Litres	×	.2642	= gals. (231 cu. in.)
Litres	÷	3.785	= gals. (231 cu. in.)
Litres	÷	28.317	= cu. ft.
Hectolitres	×	3.531	= cu. ft.
Hectolitres	×	2.838	= bu. (2150.42 cu. in.)
Hectolitres	×	.1308	= cu. yds.
Hectolitres	×	26.42	= gals. (231 cu. in.)
Weight			
Grams	×	15.432	= grains (Act. Cong.)
Grams	÷	981.	= dynes
Grams (water)	÷	29.57	= fl. oz.
Grams	÷	28.35	= oz. avoirdupois
Kilo-grams	×	2.2046	= lbs.

Metric Conversion Table (Cont.)

Weight

Kilo-grams	×	35.27	= oz. avoirdupois
Kilo-grams	×	.0011023	= tons (2000 lbs.)
Tonneau (Metric ton)	×	1.1023	= tons (2000 lbs.)
Tonneau (Metric ton)	×	2204.6	= lbs.

Unit Weight

Grams per cu. cent.	÷	27.68	= lbs. per cu. in.
Kilo per meter	×	.672	= lbs. per ft.
Kilo per cu. meter	×	.06243	= lbs. per cu. ft.
Kilo per Cheval	×	2.235	= lbs. per h. p.
Grams per liter	×	.06243	= lbs. per cu. ft.

Pressure

Kilo-grams per sq. cm.	×	14.223	= lbs. per sq. in.
Kilo-grams per sq. cm.	×	32 843	= ft. of water (60°F.)
Atmospheres (international)	×	14.696	= lbs. per sq. in

Energy

Joule	×	.7376	= ft. lbs.
Kilo-gram meters	×	7.233	= ft. lbs.

Power

Cheval vapeur	×	.9863	= h. p.
Kilo-watts	×	1.341	= h. p.
Watts	÷	746.	= h. p.
Watts	×	.7373	= ft. lbs. per sec

Miscellaneous

Kilogram calorie	×	3.968	= B. t. u.
Standard gravity (Sea level 45° lat.)	÷	980.665	= centimeters per sec. per sec.
Frigories/hr. (French)	÷	3023.9	= Tons refrigeration

The following pages show temperatures on Fahrenheit and Centigrade thermometers.

Equivalent Temperature Readings for Fahrenheit and Centigrade Scales

Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.
-459.4	-273	-21.	-29.4	17.6	-8.	56.	13.3
-436.	-270.	-20.2	-29.	18.	-7.8	57.	13.9
-418.	-260.	-20.	-28.9	19.	-7.2	57.2	14.
-400.	-240.	-19.	-28.3	19.4	-7.	58.	14.4
-382.	-230.	-18.4	-28.	20.	-6.7	59.	15.
-364.	-220.	-18.	-27.8	21.	-6.1	60.	15.6
-346.	-210.	-17.	-27.2	21.2	-6.	60.8	16.
-328.	-200.	-16.6	-27.	22.	-5.6	61.	16.1
-310.	-190.	-16.	-26.7	23.	-5.	62.	16.7
-292.	-180.	-15.	-26.1	24.	-4.4	62.6	17.
-274.	-170.	-14.8	-26.	24.8	-4.	63.	17.2
-256.	-160.	-14.	-25.6	25.	-3.9	64.	17.8
-238.	-150.	-13.	-25.	26.	-3.3	64.4	18.
-220.	-140	-12.	-24.4	26.6	-3.	65.	18.3
-202.	-130.	-11.2	-24.	27.	-2.8	66.	18.9
-184.	-120.	-11.	-23.9	28.	-2.2	66.2	19.
-166.	-110.	-10.	-23.3	28.4	-2.	67.	19.4
-148.	-100.	-9.4	-23.	29.	-1.7	68.	20.
-139.	-95.	-9.	-22.8	30.	-1.1	69.	20.6
-130.	-90.	-8.	-22.2	30.2	-1.	69.8	21.
-121.	-85.	-7.6	-22.	31.	-0.6	70.	21.1
-112.	-80.	-7.	-21.7	32.	0.	71.	21.7
-103.	-75	-6.	-21.1	33.	+0.6	71.6	22.
-94.	-70.	-5.8	-21.	33.8	1.	72.	22.2
-85.	-65.	-5.	-20.6	34.	1.1	73.	22.8
-76.	-60.	-4.	-20.	35.	1.7	73.4	23.
-67.	-55.	-3.	-19.4	35.6	2.	74.	23.3
-58.	-50.	-2.2	-19.	36.	2.2	75.	23.9
-49.	-45.	-2.	-18.9	37.	2.8	75.2	24.
-40.	-40.	-1.	-18.3	37.4	3.	76.	24.4
-39.	-39.4	-0.4	-18.	38.	3.3	77.	25.
-38.2	-39.	0.	-17.8	39.	3.9	78.	25.6
-38.	-38.9	+1.	-17.2	39.2	4.	78.8.	26.
-37.	-38.3	1.4	-17.	40.	4.4	79.	26.1
-36.4	-38.	2.	-16.7	41.	5.	80.	26.7
-36.	-37.8	3.	-16.1	42.	5.6	80.6	27.
-35.	-37.2	3.2	-16.	42.8	6.	81.	27.2
-34.6	-37.	4.	-15.6	43.	6.1	82.	27.8
-34.	-36.7	5.	-15.	44.	6.7	82.4	28.
-33.	-36.1	6.	-14.4	44.6	7.	83.	28.3
-32.8	-36.	6.8	-14.	45.	7.2	84.	28.9
-32.	-35.6	7.	-13.9	46.	7.8	84.2	29.
-31.	-35.	8.	-13.3	46.4	8.	85.	29.4
-30.	-34.4	8.6	-13.	47.	8.3	86.	30.
-29.2	-34.	9.	-12.8	48.	8.9	87.	30.6
-29.	-33.9	10.	-12.2	48.2	9.	87.8	31.
-28.	-33.3	10.4	-12.	49.	9.4	88.	31.1
-27.4	-33.	11.	-11.7	50.	10.	89.	31.7
-27.	-32.8	12.	-11.1	51.	10.6	89.6	32.
-26.	-32 2	12.2	-11.	51.8	11.	90.	32.2
-25.6	-32.	13.	-10.6	52.	11.1	91.	32.8
-25.	-31.7	14.	-10.	53.	11.7	91.4	33.
-24.	-31.1	15.	-9.4	53.6	12.	92.	33.3
-23.8	-31.	15.8	-9.	54.	12.2	93.	33.9
-23.	-30.6	16.	-8.9	55.	12.8	93.2	34.
-22.	-30.	17.	-8.3	55.4	13.	94.	34.4

Equivalent Temperature Readings for Fahrenheit and Centigrade Scales

Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.
95.	35.	134.	56.7	172.4	78.	211.	99.4
96.	35.6	134.6	57.	173.	78.3	212.	100.
96.8	36.	135.	57.2	174.	78.9	213.	100.6
97.	36.1	136.	57.8	174.2	79.	213.8	101.
98.	36.7	136.4	58.	175.	79.4	214.	101.1
98.6	37.	137.	58.3	176.	80.	215.	101.7
99.	37.2	138.	58.9	177.	80.6	215.6	102.
100.	37.8	138.2	59.	177.8	81.	216.	102.2
100.4	38.	139.	59.4	178.	81.1	217.	102.8
101.	38.3	140.	60.	179.	81.7	217.4	103.
102.	38.9	141.	60.6	179.6	82.	218.	103.3
102.2	39.	141.8	61.	180.	82.2	219.	103.9
103.	39.4	142.	61.1	181.	82.8	219.2	104.
104.	40.	143.	61.7	181.4	83.	220.	104.4
105.	40.6	143.6	62.	182.	83.3	221.	105.
105.8	41.	144.	62.2	183.	83.9	222.	105.6
106.	41.1	145.	62.8	183.2	84.	222.8	106.
107.	41.7	145.4	63.	184.	84.4	223.	106.1
107.6	42.	146.	63.3	185.	85.	224.	106.7
108.	42.2	147.	63.9	186.	85.6	224.6	107.
109.	42.8	147.2	64.	186.8	86.	225.	107.2
109.4	43.	148.	64.4	187.	86.1	226.	107.8
110.	43.3	149.	65.	188.	86.7	226.4	108.
111.	43.9	150.	65.6	188.6	87.	227.	108.3
111.2	44.	150.8	66.	189.	87.2	228.	108.9
112.	44.4	151.	66.1	190.	87.8	228.2	109.
113.	45.	152.	66.7	190.4	88.	229.	109.4
114.	45.6	152.6	67.	191.	88.3	230.	110.
114.8	46.	153.	67.2	192.	88.9	231.	110.6
115.	46.1	154.	67.8	192.2	89.	231.8	111.
116.	46.7	154.4	68.	193.	89.4	232.	111.1
116.6	47.	155.	68.3	194.	90.	233.	111.7
117.	47.2	156.	68.9	195.	90.6	233.6	112.
118.	47.8	156.2	69.	195.8	91.	234.	112.2
118.4	48.	157.	69.4	196.	91.1	235.	112.8
119.	48.3	158.	70.	197.	91.7	235.4	113.
120.	48.9	159.	70.6	197.6	92.	236.	113.3
120.2	49.	159.8	71.	198.	92.2	237.	113.9
121.	49.4	160.	71.1	199.	92.8	237.2	114.
122.	50.	161.	71.7	199.4	93.	238.	114.4
123.	50.6	161.6	72.	200.	93.3	239.	115.
123.8	51.	162.	72.2	201.	93.9	240.	115.6
124.	51.1	163.	72.8	201.2	94.	240.8	116.
125.	51.7	163.4	73.	202.	94.4	241.	116.1
125.6	52.	164.	73.3	203.	95.	242.	116.7
126.	52.2	165.	73.9	204.	95.6	242.6	117.
127.	52.8	165.2	74.	204.8	96.	243.	117.2
127.4	53.	166.	74.4	205.	96.1	244.	117.8
128.	53.3	167.	75.	206.	96.7	244.4	118.
129.	53.9	168.	75.6	206.6	97.	245.	118.3
129.2	54.	168.8	76.	207.	97.2	246.	118.9
130.	54.4	169.	76.1	208.	97.8	246.2	119.
131.	55.	170.	76.7	208.4	98.	247.	119.4
132.	55.6	170.6	77.	209.	98.3	248.	120.
132.8	56.	171.	77.2	210.	98.9	249.	120.6
133.	56.1	172.	77.8	210.2	99.	249.8	121.